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CALIFORNIA  
ENERGY  
COMMISSION

**Biomass in Solid Waste in California:  
Utilization and Policy Alternatives**

**DRAFT**

**PIER COLLABORATIVE REPORT**



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## **Abstract**

In 1989 California passed landmark legislation (AB 939) installing a framework for integrated solid waste management. This framework included identification and regulation of all solid waste disposal facilities in the state to ensure that best practices for landfill management and design were being followed, implementation of waste diversion and recycling programs, and a disposal reporting system. A key component of the act was the establishment of waste diversion-from-landfill goals (25% of generated waste to be diverted by 1995 and 50% by 2000). Using the adopted accounting method, the 50% diversion goal has essentially been achieved on a state-wide basis. However, the amount of material still disposed in California landfills is substantial (41 million tons in 2004 and projected to increase) and includes 26 million tons of biogenic material (including green ADC) and 6 million tons of non-recycled plastics (representing potential primary energy of 269 PJ and 144 PJ respectively). In the interest of reducing the organic content of the disposed material, a range of options exist including conversion to power and other products and policy initiatives. Waste management based on reducing per capita disposal rather than a diversion based approach may be considered in improving future waste management and making better utilization of the biomass resource. Progressive energy and solid waste policies in Europe have advanced the state of technology for waste management and conversion to energy and results are reviewed in the context of application within California. Applying producer take-back policies for packaging material might reduce the existing landfill stream by 20%, or by limiting the bulk energy content of the disposed waste stream to a maximum of  $6 \text{ MJ kg}^{-1}$  could reduce the landfill stream as much as 63%.

## Summary Points

- In 2004, 41 million tons of MSW were disposed including 23.1 million tons (60% of total) of biogenic material and 5.7 million tons (13%) of non-recycled plastics (which includes landfilled textiles and carpet) and an additional 2.6 million tons of greenwaste was used as alternative daily cover.
- The potential energy from annually landfilled MSW is substantial.
  - Primary or chemical energy of disposed stream is equivalent to the energy in 67 million barrels of crude oil or 2600 MW of electric potential.
- Landfill waste-in-place generate an estimated 80 billion cubic feet per year of landfill gas.
- California per capita landfill disposal has remained fairly constant at 2200 lbs. per person per year since 1995.
- California per capita landfill disposal (adjusted down for comparison) is a third more than the US average and more than twice that of Western Europe.
- Total annual landfill disposal is expected to increase as population grows.
- Landfill material restrictions have been implemented in Europe (to reduce environmental impacts from landfills).
- Europe classifies all thermal conversion systems as 'incineration' but because they have set strict environmental performance standards, rather than prescribed technologies, thermal conversion in Europe is a significant component of their strategies to reduce landfill disposal and GHGs generated from the practice.
- England has implemented a landfill 'cap and trade' scheme in order to meet the EU landfill directive targets for biodegradable waste (began in April, 2005). Jurisdictions that exceed the limit will be fined £150 for every metric tonne they are over the limit. This is believed to be the first of its kind in the municipal waste sector.
- There is need for a comprehensive LCA of integrated waste management in California (to include the full range of waste management techniques and strategies including composting and the various conventional recycling methods [including emissions and conditions of recycling processes overseas that receive California waste]).
- To address and possibly reaffirm legacy decisions that led to material 'highest and best use' and the waste hierarchy.
- Dioxin emissions from US solid waste combustion have decreased by 99.9% since 1987.
- Waste management LCA studies from Europe and South Korea consistently rank landfills as having the worst environmental impact, followed by open-air composting. Anaerobic digestion w/ energy recovery and solid combustion with energy recovery consistently rank having least environmental impacts of waste management options.
- Policies and technologies that can reduce per capita waste disposal should be implemented in place of a diversion based approach.
- Energy and solid waste policies in Europe have advanced the state of technology for waste management and conversion. There are potential opportunities to adapt these policies and advanced systems in Europe to the emerging market in California.

## Table of Contents

Abstract .....	iii
Summary Points .....	iv
Figures and Tables .....	vi
Introduction .....	1
Current MSW Biomass Utilization .....	1
Resource Potential .....	2
Waste-in-Place and LFG Estimates .....	5
Per Capita Disposal and Landfill Flow Scenarios .....	9
Since AB 939 .....	9
Disposal comparison with Western Europe .....	10
Projections for Future Landfill Disposal .....	12
Landfill Disposal ‘Cap and Trade’ .....	15
Conversion Technology and Landfill Disposal Reduction .....	15
Conversion Technology Capacity to Offset Disposal Increases .....	16
Status of Conversion Technology Investigation and Policy .....	17
Need for Comprehensive LCA .....	19
Improvements in solid waste combustion emissions .....	20
Results from LCA of waste management scenarios .....	24
MSW and the California RPS .....	27
Consideration of MSW as a renewable resource in Europe .....	28
Discussion .....	29
Policies .....	29
Conclusions and Recommendations .....	30
Appendix .....	32
Potential energy calculation notes: .....	32

## Figures and Tables

Figure 1. California landfilled waste stream by material type.....	3
Figure 2. Waste stream component disposal amounts and potential primary energy.....	5
Figure 3. Waste-in-place (billion tons) distribution for California landfills.....	6
Figure 4. California landfills with WIP of 10 million tons or more .....	6
Figure 5. LFG methane and electricity generation potential from conventional landfills in California .....	8
Figure 6. LFG methane and electricity generation potential from conventional landfills and switching to bioreactor landfills post 2004 .....	8
Figure 7. Landfill disposal and estimated diversion rate since AB 939 implementation ...	9
Figure 8. Per-capita waste generation and disposal in California with associated waste diversion rate.....	10
Figure 9. Per-capita landfill disposal for US and Western Europe.....	12
Figure 10. Historical and projected landfill amounts for California.....	13
Figure 11. Historical and predicted landfill amounts including ‘new use’ of material ....	16
Figure 12. US dioxin emission inventory by source type.....	21
Figure 13. Dioxin emission concentrations for several technology types .....	22
Figure 14. Dioxin emissions from conversion of MSW .....	23
Figure 14 b Dioxin emissions per ton of WIP from combustion of landfill gas.....	23
Figure 15. Results from four LCA methodologies (or LCIA for life cycle impact assessment) used to compare solid waste management scenarios in Korea .....	24
Figure 16. Relative impact from treatment options for biogenic wastes for a scenario in Europe .....	26

## Tables

<b>Table 1 California annual disposed waste characterization (wet basis) and potential energy .....</b>	<b>4</b>
<b>Table 2. WIP Distribution by landfill type .....</b>	<b>5</b>

## Introduction

In 1989 California passed landmark legislation (AB 939) installing a framework for integrated solid waste management. This framework included identification and regulation of all solid waste disposal facilities in the state to ensure that best practices for landfill management were being followed, the implementation of waste diversion and recycling programs, and disposal reporting systems. A key component of the enactment was establishment of goals for diversion of generated waste from landfills (25% of generated waste was required to be diverted by 1995 and 50% by 2000). Upon implementation of the program, solid waste generation in the state was measured in 1990 becoming the base year for future estimates. The diverted fraction at that time was about 17% (i.e., 83% of identified solid waste was being landfilled). For the years 2003 and 2004, the estimated diverted fraction was about 48%. Per capita waste disposal decreased initially but has remained essentially constant since 1995. (Fig. 8) The amount of material still disposed in California landfills is substantial. In 2004, 40.9 million tons were disposed including 23.1 million tons of biogenic material and 5.7 million tons of non-recycled plastics (which includes landfilled textiles and carpet). An additional 2.6 million tons of greenwaste was used as alternative daily cover (ADC) and buried in landfills.

Even if diversion continues to increase, the amount of resource sent to landfill is expected to increase unless consumption patterns or policy change or new markets develop for the material. The current disposed waste stream has large potential value if used for energy or chemical feedstocks. Increases in waste disposal will burden the environment and infrastructure in the near and long term so it is advantageous for the State to reduce and even eliminate the solid waste burden.

Energy and solid waste policy in Europe have taken different approaches than those in California or the US. Solid waste policies in the EU have evolved from Kyoto Protocol greenhouse gas reduction goals, including requirements for increased renewable energy and decreases in methane emissions from landfills, and are creating strong incentives for landfill alternatives. This has advanced the state of technology for waste management and conversion to energy. An understanding of the European situation in this regard may yield potential opportunities to adapt policies and advanced systems in Europe to the emerging market in California.

## Current MSW Biomass Utilization

Since 1990, the number of composting and mulching operations in California has grown from 10 to approximately 200. Several of the State's 31 biomass power facilities have access to urban wood fuel diverted from landfill and there are 3 dedicated MSW mass burn facilities in the State. Combined, these facilities process or consume about 10 million tons per year of the biogenic solid waste generated (1.7 million tons of urban wood wastes and 900,000 tons of mixed wastes are burned for power).<sup>1,2</sup>

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<sup>1</sup> Cotton, M. (2004). "Second Assessment of California's Compost- and Mulch-Producing Infrastructure." 442-04-007, CIWMB.

There are some 150 active landfills accepting MSW in California (hazardous waste and used tires are disposed in facilities separate from MSW sites). There are more than 2750 landfills that are closed, inactive, illegal, or abandoned in the state. Currently, some 60 landfills in the State are recovering landfill gas for use as energy (LFGTE), which includes 55 that generate electricity on site with a combined capacity of 280 MWe and 10 facilities that use LFG directly for heat production or sent offsite via pipeline. An additional 100 landfills are recovering and flaring the gas with no energy recovery. Approximately 10 landfills are considering new LFGTE installations.<sup>3,4,5</sup> A full scale landfill bioreactor is being demonstrated at the Yolo County landfill.

### Resource Potential

Despite substantial recycling, diversion and energy recovery efforts, the biomass and plastics material still being disposed represent a considerable resource.

Of the 40.9 million tons landfilled, some 23.1 million tons are of biological origin (biogenic), 5.7 million tons are plastics and textiles (the latter assumed to be all synthetic textiles), and the remaining 12.1 million tons are mineral and other inorganic material (glass, metal, non-wood construction/demolition waste; see Figure 1).

Table 1 contains an analysis of the total energy and the electricity generation potential represented by the California MSW stream currently being landfilled. For each component of the waste stream, the table lists amount landfilled (wet and dry basis), typical moisture and higher heating values (HHV) and primary (or chemical) and electrical energy potentials. Figure 2 compares waste components by weight and energy content.

The potential energy from California annually landfilled MSW is substantial. Primary or chemical energy of disposed stream is about 413 PJ (about 0.39 Quad)<sup>6</sup> which is equivalent to the energy in 67 million barrels of crude oil. Alternatively, biomass in the landfill disposal stream (23.1 million tons plus 2.6 million tons of green ADC) could support about 1750 MWe of electricity generation with another 900 MWe coming from the plastics and textiles components.<sup>7</sup>

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<sup>2</sup> Williams, R. B., Jenkins, B. M., and Nguyen, D. (2003). "Solid Waste Conversion- A review and database of current and emerging technologies." Final Report. CIWMB contract IWM-C0172.

<sup>3</sup> CIWMB Solid Waste Information System (SWIS) (<http://www.ciwmb.ca.gov/swis/search.asp>) Accessed October, 2005.

<sup>4</sup> Simons, G., Zhang, Z., and Redding, P. T., "Landfill Gas-To-Energy Potential In California." *California Energy Commission Staff Report 500-02-041VI*, (2002).

<sup>5</sup> Walker, S. (2005). "Compilation of landfill waste-in-place (WIP) and landfill gas-to-energy information." November 30 Memorandum to Howard Levinson, CIWMB.

<sup>6</sup> PJ = 10<sup>15</sup> J (petajoule). 1000 PJ are approximately equal to 1 Quad (1 Q = 10<sup>15</sup> Btu = 1,055 PJ)

<sup>7</sup> See Appendix for brief description of the gross electricity generation potential from MSW estimate.



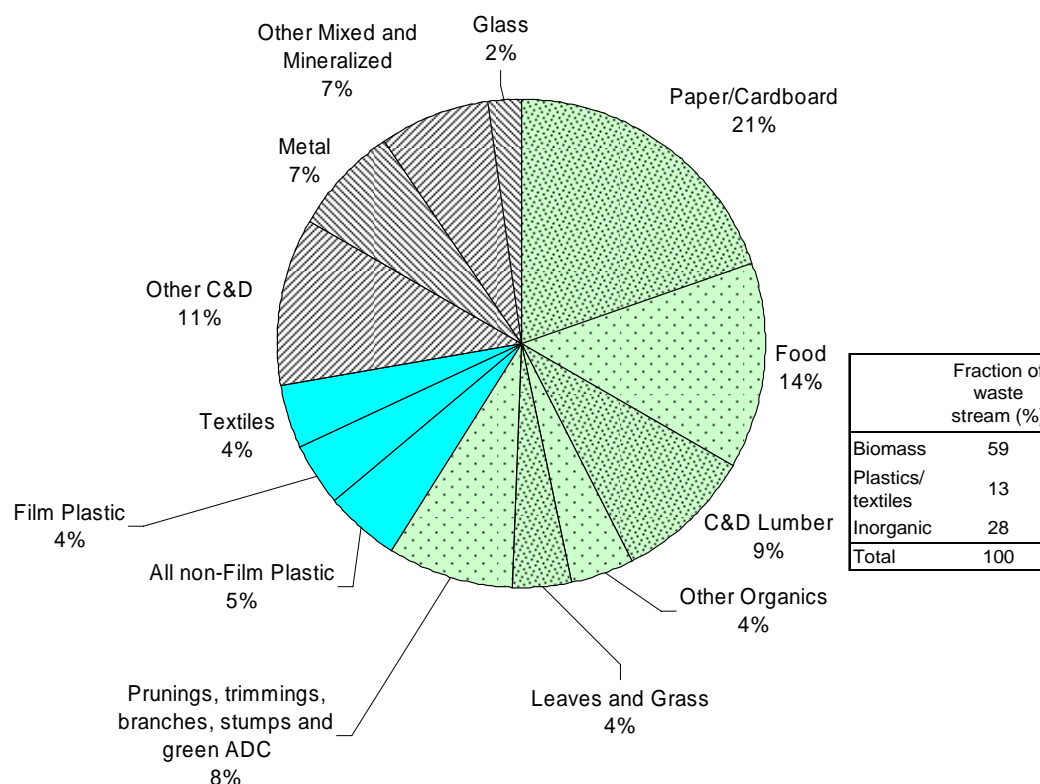


Figure 1. California landfilled waste stream by material type (adapted from <sup>8</sup>)

The sum of nearly 2700 MWe is about 4% of in-state generating capacity, and the electrical energy potential is about 8% of state consumption.<sup>9</sup> Electrical potential from the renewable (biogenic) portion of the stream is equivalent to about 50% of the current amount of renewable electricity used in the State from all sources.<sup>10</sup> Full conversion is unlikely, but solid waste nonetheless represents a significant potential source of energy for the state.<sup>11</sup>

<sup>8</sup> Cascadia Consulting Group. (2004). "Statewide waste characterization study." Contractor's report to CIWMB. Publication #340-04-005. Available at; <http://www.ciwmb.ca.gov/Publications/default.asp?pubid=1097>

<sup>9</sup> Electricity consumption in California is ~ 275 TWh y<sup>-1</sup> and renewable electricity accounts for ~ 29,000 GWh y<sup>-1</sup>. Source: California Energy Commission ([http://www.energy.ca.gov/electricity/gross\\_system\\_power.html](http://www.energy.ca.gov/electricity/gross_system_power.html)). The high energy potential relative to capacity is due to the high capacity factors of biomass generating facilities.

<sup>10</sup> [http://www.energy.ca.gov/electricity/gross\\_system\\_power.html](http://www.energy.ca.gov/electricity/gross_system_power.html). To the extent that plastics made from petroleum or tires are used in conversion to energy, that portion of the energy produced would not be considered renewable.

<sup>11</sup> This analysis applies only to the current waste stream going to landfill (including green ADC). CIWMB estimates that approximately 8 million tons of MSW material go to compost, or solid fuel combustion facilities annually and only ~31% (4.8 million tons/y) of waste paper is diverted ((1997), <http://www.ciwmb.ca.gov/Paper/> Accessed October, 2003) The amount of urban wood waste or C&D lumber estimated to be currently consumed in power production facilities is 1.5 million t y<sup>-1</sup>.

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**Table 1 California annual disposed waste characterization (wet basis) and potential energy. \***

	Landfilled <sup>a</sup> 2004 (million tons)	wt % of Total	Moisture <sup>b</sup> (%wb)	Landfilled (million dry tons)	Ash / mineral matter (million tons)	HHV <sup>b</sup> (BTU/dry lb)	Chemical Energy			Electricity Potential <sup>d</sup>		
							Potential (PJ) <sup>c</sup>	Equivalent barrels of oil (millions)	Fraction of total (%)	(MWe)	(GWh y-1)	(rank)
Paper/Cardboard	8.6	19.7	10	7.7	0.5	7650	125	20.2	30	791	6928	1
Food	6.0	13.7	70	1.8	0.3	6000	23	3.7	6	204	1790	6
C&D Lumber	3.9	9.0	12	3.5	0.2	6450	14	2.3	3	384	771	8
Prunings, trimmings, branches, stumps and green ADC <sup>e</sup>	3.7	8.4	40	2.2	0.1	8175	9	1.5	2	240	371	9
Other Organics	1.8	4.1	4	1.7	0.1	3800	38	6.1	9	88	2105	5
Leaves and Grass	1.7	3.9	60	0.7	0.2	8300	61	9.8	15	42	3365	3
<b>Biomass Components of MSW Total<sup>e</sup></b>	<b>25.7</b>	<b>59.0</b>		<b>17.6</b>	<b>1.3</b>		<b>269</b>	<b>43.6</b>	<b>65.1</b>	<b>1750</b>	<b>15,330</b>	
All non-Film Plastic	2.1	4.8	0.2	2.1	0.0	9475	42	6.8	10	264	2313	4
Film Plastic	1.8	4.1	0.2	1.8	0.1	19400	73	11.9	18	466	4083	2
Textiles	1.8	4.2	10	1.7	0.1	8325	29	4.7	7	184	1614	7
<b>Non-Biomass Organic Components of MSW Total</b>	<b>5.7</b>	<b>13.2</b>		<b>5.5</b>	<b>0.22</b>		<b>144</b>	<b>23.4</b>	<b>34.9</b>	<b>914</b>	<b>8011</b>	
Other C&D	4.9	11.3		4.9	4.9	-	-	-	-	-	-	
Metal	3.1	7.2		3.1	3.1	-	-	-	-	-	-	
Other Mixed and Mineralized	3.1	7.1		3.1	3.1	-	-	-	-	-	-	
Glass	0.9	2.2		0.9	0.9	-	-	-	-	-	-	
<b>Inorganic Components of MSW Total</b>	<b>12.1</b>	<b>27.8</b>		<b>12.1</b>	<b>12.1</b>	<b>0</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	
<b>Totals<sup>e</sup></b>	<b>43.5</b>	<b>100</b>	<b>19</b>	<b>35.2</b>	<b>13.7</b>	<b>(ave.) 5300</b>	<b>413</b>	<b>67</b>	<b>100</b>	<b>2664</b>	<b>23,341</b>	

a) 2004 disposal amount and 2003 California waste stream composite data from: (2004). "Statewide waste characterization study." Cascadia Consulting Group's report to CIWMB. Publication #340-04-005 (<http://www.ciwmb.ca.gov/Publications/default.asp?pubid=1097>), Accessed 1 Sept., 2005

b) Adapted from Tchobanoglous, G., Theisen, H. and Vigil, S.(1993),"Integrated Solid Waste Management", Chapter 4, McGraw-Hill, New York & Themelis, N. J., Kim, Y. H., and Brady, M. H. (2002). "Energy recovery from New York City municipal solid wastes." Waste Management & Research, 20(3), 223-233.

c) PJ = 10<sup>15</sup> J (petajoule). 1000 PJ are approximately equal to 1 Quad (1 Q = 1015 Btu = 1,055 PJ)

d) Electricity calculations assume thermal conversion means for low moisture stream (paper/cardboard, other organics, C&D Lumber, all plastics and textiles) and biological means (anaerobic digestion) for high moisture components (food and green waste). Energy efficiency of conversion of matter to electricity by thermal means is assumed to be 20%. Biomethane potentials of 0.29 and 0.14 g CH<sub>4</sub>/g VS for food and leaves/grass mixture respectively are assumed for biogas production which is converted at 30% thermal efficiency in reciprocating engines. Capacity factor of 1 is used.

e). Includes 2.6 million tons of ADC composed of green waste. See; <http://www.ciwmb.ca.gov/lgcentral/DRS/Reports/Statewide/ADCMatTyp.asp>

\* adapted from Williams et al., (2003) with 2004 update and inclusion of green ADC

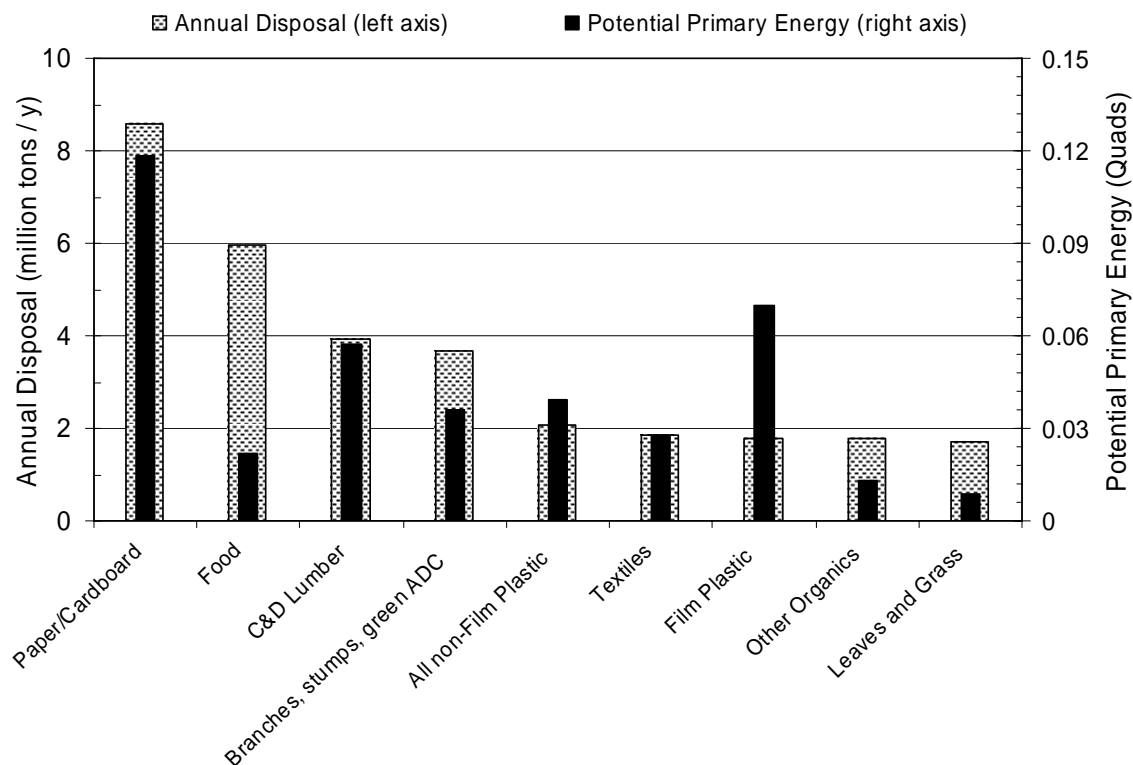


Figure 2. Waste stream component disposal amounts and potential primary energy (annual basis).

### Waste-in-Place and LFG Estimates

Because landfill gas originates from the anaerobic decay of waste in the landfill, current as well as future LFG production depends on the amount of buried waste or waste-in-place (WIP).

The California Integrated Waste Management Board estimates WIP is 1.1 billion tons for 364 California landfills (active and closed) that have WIP of 10,000 tons or greater (includes biodegradable ADC).<sup>12</sup> Some 146 landfills are active and account for more than 60% of total WIP (see Table 2 and Figure 3). The 31 landfills in California with WIP > 10 million tons (10 of which are closed) account for about 65% of the state's WIP (Figure 4).

**Table 2. WIP Distribution by landfill type**

	No.	WIP (million tons)	% of Total WIP
Active LFs	146	725	64
Closed LFs	219	399	36
Totals	365	1,125	100

<sup>12</sup> Walker, S. (2005) Op. Cit.

Data have also been compiled by US EPA as part of the landfill methane outreach program (LMOP). The LMOP data yield a total waste-in-place since 1922 of 937 million tons.<sup>13</sup>

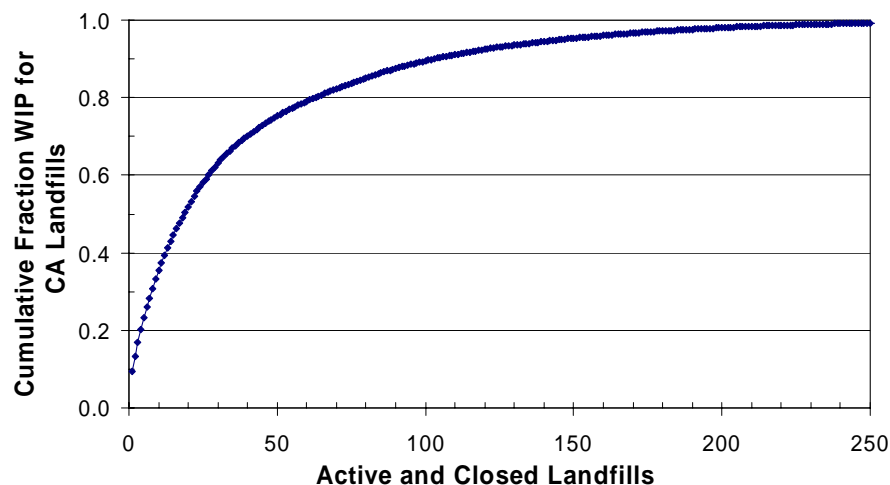


Figure 3. Waste-in-place (billion tons) distribution for California landfills (Adapted from <sup>14, 15</sup>)

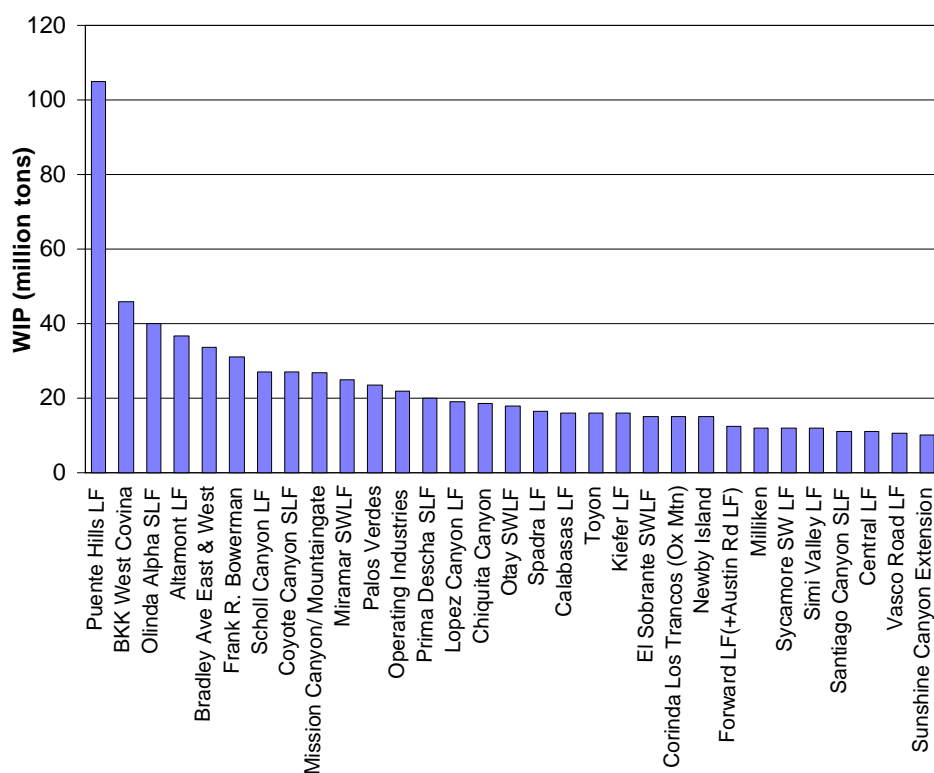


Figure 4. California landfills with WIP of 10 million tons or more (adapted from <sup>16</sup>)

<sup>13</sup> For 217 landfills with existing or potential landfill gas to energy recovery. Source: USEPA, Landfill Methane Outreach Program, <http://www.epa.gov/lmop/proj/index.htm>

<sup>14</sup> Scott Walker. (2005). CIWMB. Op. Cit.

<sup>15</sup> Williams, R. B., Jenkins, B. M., and Kornbluth, K. (2006). "Initial Estimates of Hydrogen Production Potential from California Landfill Gas." Draft Working Paper (unpublished).

<sup>16</sup> Ibid.

Estimating annual landfill gas production is based on waste in place and waste additions over time along with assumptions regarding the waste composition or biodegradability, gas generation rate, and gas composition. Landfill gas generation for the period 2005 – 2020 was estimated on a statewide basis for approximately 1 billion tons of waste landfilled since 1970. Disposal post-1990 contributes most of the landfill gas by 2020.<sup>17</sup> The potential for increasing generation capacity through the adoption of bioreactor landfills is also briefly explored.

Figure 5 presents LFG methane and electricity generation potential from conventional landfills in California based on WIP and future disposal assumptions.<sup>18</sup> Figure 6 shows LFG methane and electricity potential similar to Figure 5 but assumes post 2005 waste is deposited in bioreactor landfills (same ultimate biomethane potential but increased rate constant  $k$  from 0.04 to 0.08  $y^{-1}$ ).

The total methane generation for conventional landfilling assuming no change in the current per capita waste disposal rate increases from 80 to 125 billion cubic feet per year (BCF/y) between 2005 and 2025 with potential (or technical) electricity generation capacity increasing from 550 to more than 800 MWe (Figure 2). Note that the potential electricity generation from the biomass fraction of the current disposed waste stream is about 1750 MWe if it were converted via thermochemical and biochemical means before landfill disposal (see Table 1). The methane yield from landfills in the state is about 5% of current natural gas consumption (2,572 BCF/y in 2004).<sup>19</sup>

Landfill gas will remain an important resource for power generation through 2020 even if the state acts to further reduce waste disposal. The large amount of waste already in place will continue to generate gas well into the future. Bioreactor landfills employing leachate recirculation and membrane covers have the potential to increase the rate of gas generation from new waste disposal due to enhanced conditions for the microorganisms and faster gas production rates.

High-rate in-vessel digestion is also being developed for MSW as are a number of other thermochemical and biochemical concepts.

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<sup>17</sup> Gildart, M., Jenkins, B. M., Williams, R. B., Yan, L., Aldas, R. E., and Matteson, G., C. (2005). "An Assessment of Biomass Resources in California -Draft Report." *CEC PIER Contract 500-01-016*, California Biomass Collaborative.

<sup>18</sup> Model estimates based on first order decay of waste using USEPA AP-42 parameters (methane generation potential = 100  $m^3 Mg^{-1}$ , methane generation rate constant  $k = 0.04 y^{-1}$ ) for disposal post-1970. Gross electric capacity based on total methane generation, 30% methane conversion efficiency, and 85% capacity factor. Potential electric capacity assumes 67% methane recovery (recovered methane), 30% electrical conversion efficiency, and 85% capacity factor. MSW disposal assumes a population growth rate of 1.43%  $y^{-1}$  beyond 2004 and no change in current annual per capita disposal rate. Actual population data used for period 1970-2004, actual waste disposal data used for period 1990-2004. Disposal pre-1990 estimated from population. Methane production is estimated only for waste disposed post-1970.

<sup>19</sup> Gildart et. al. (2005). Op Cit

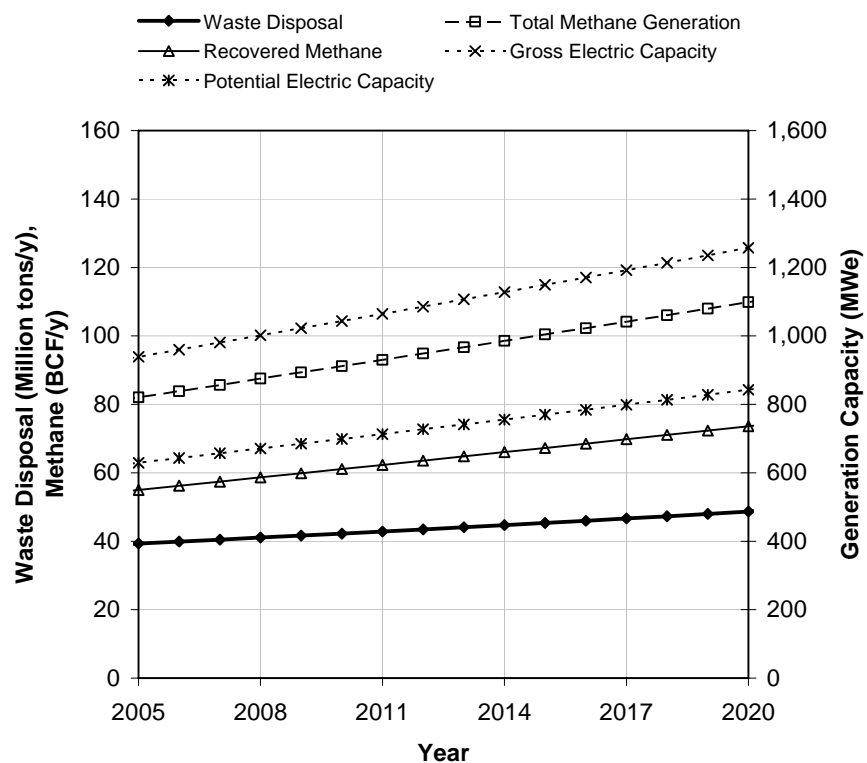


Figure 5. LFG methane and electricity generation potential from conventional landfills in California.<sup>20</sup>

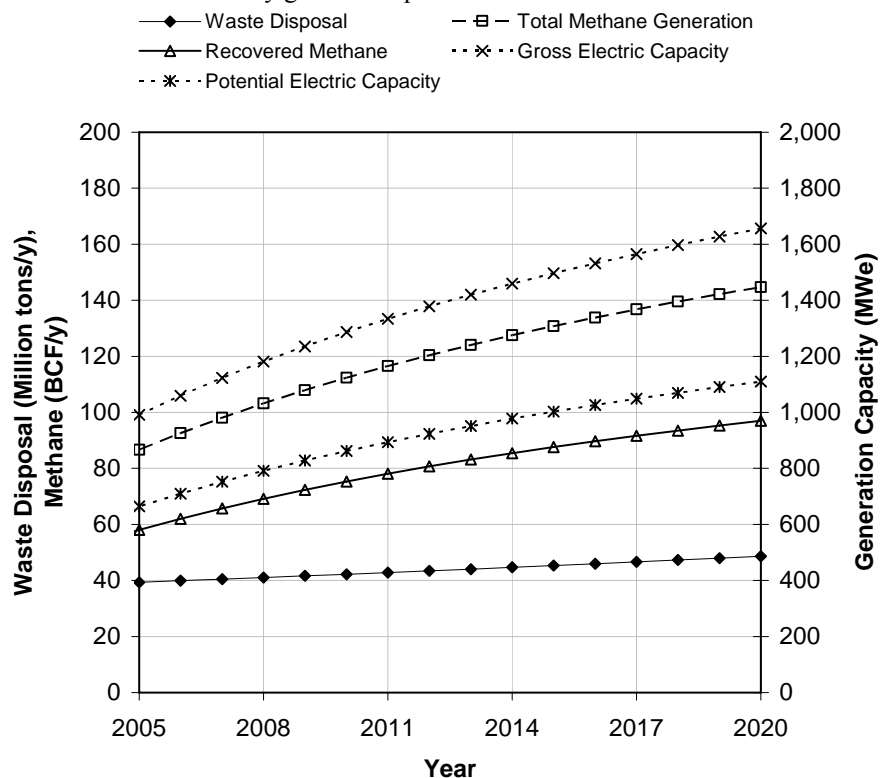


Figure 6. LFG methane and electricity generation potential from conventional landfills and switching to bioreactor landfills post 2004.<sup>21</sup>

<sup>20</sup> Ibid.

## Per Capita Disposal and Landfill Flow Scenarios

### Since AB 939

Since implementation of AB 939, waste disposed in landfill decreased from 44 million tons/yr in 1989 to a low of about 35 million tons in 1996 and has been increasing since, reaching nearly 41 million tons in 2004. The estimated waste diversion (defined as the fraction of all generated solid waste from industrial, commercial, construction and demolition, and residential sources that was not disposed in landfill) has steadily increased from 10 – 48% during the 1989 to 2004 period (Figure 7). Population has increased from 29.4 to 36.5 million people during the same period (average annual increase of 1.3%) and is expected to continue increasing reaching 45 million by 2020 and 48 to 56 million by 2040.<sup>22, 23, 24</sup> Rising population will burden much of the state's infrastructure, including that for solid waste management.

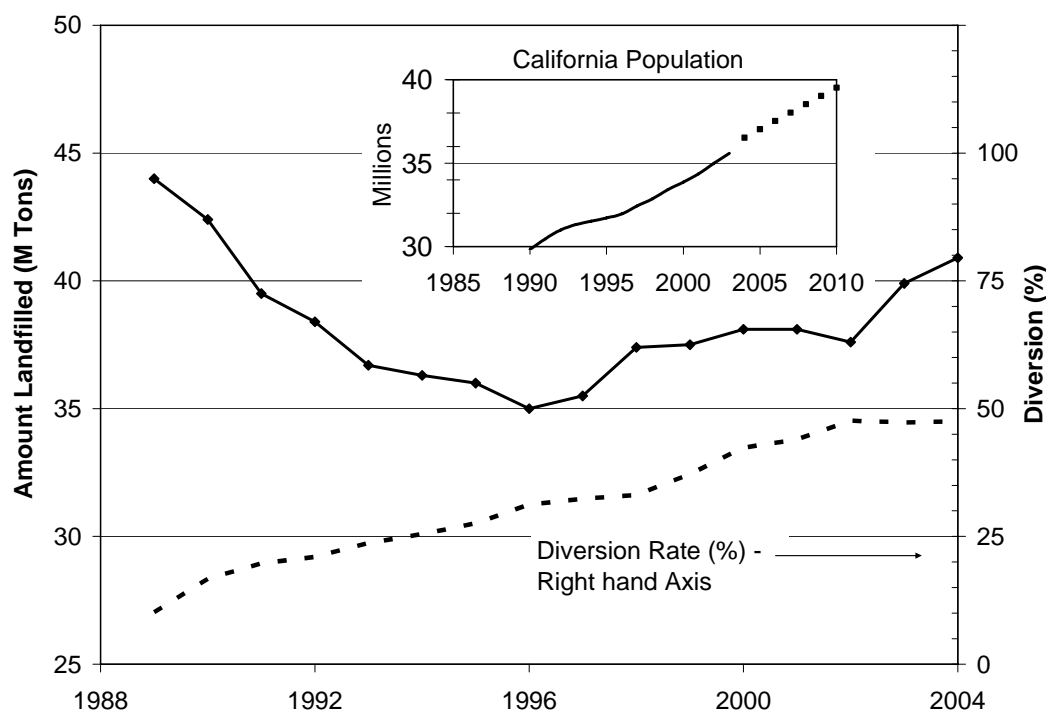


Figure 7. Landfill disposal and estimated diversion rate since AB 939 implementation

The per capita disposal amount initially declined but has remained fairly constant at 2200 lbs.  $\text{ca}^{-1} \text{y}^{-1}$  since 1995 while the estimated per capita waste generation has grown by 39% from its low in 1993 to 4265 lbs.  $\text{ca}^{-1} \text{y}^{-1}$  in 2004 (See Figure 8). These data are for all waste generation sources; industrial, commercial and residential.

<sup>21</sup> Ibid.

<sup>22</sup> State of California, Department of Finance, *California Current Population Survey Report: March 2004*. Sacramento, California. May 2005.

<sup>23</sup> State of California, Department of Finance, *Population Projections by Race/Ethnicity, Gender and Age for California and Its Counties 2000-2050*, Sacramento, California, May 2004.

<sup>24</sup> Hanak, E., and Baldassare, M. (2005). "California 2025 - Taking on the future." Public Policy Institute of California.

Since about 1996, the increase in estimated diversion was driven by an the increasing per capita waste generation estimate and is not due to decreasing per capita disposal that has been essentially constant. The growth in landfill disposal, therefore, has been directly related to population growth.

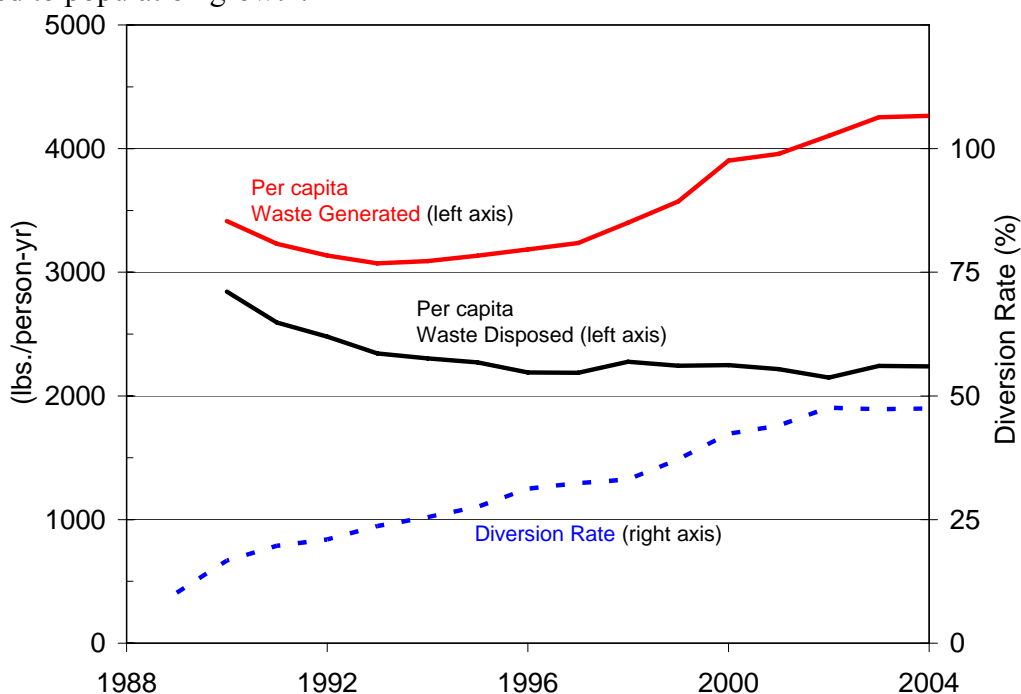


Figure 8. Per-capita waste generation and disposal in California with associated waste diversion rate (adapted from <sup>25</sup>)

### Disposal comparison with Western Europe

Average per capita MSW disposal in the EU 15 or Western Europe is about 730 lbs.  $\text{ca}^{-1} \text{y}^{-1}$  (330 kg  $\text{ca}^{-1} \text{y}^{-1}$ ). The average MSW disposal rate in Western Europe is 57%, though it varies widely from 10% in Denmark (90% recovery<sup>26</sup>) to 90% in Ireland (10% recovery). Per capita MSW generation rate is approximately 1,279 lbs.  $\text{ca}^{-1} \text{y}^{-1}$  (580 kg  $\text{ca}^{-1} \text{y}^{-1}$ ).<sup>27, 28,</sup>  
<sup>29</sup> Combustion of waste with energy recovery is an integral component of solid waste management in Europe. Annually, about 55 million tons of MSW are thermally treated and there is some 10 million tons of combustion facility annual capacity under construction.<sup>30</sup>

<sup>25</sup> Williams et al., (2003). Op Cit.

<sup>26</sup> NOTE: In Europe, the term “recovery” means recycling, composting and energy recovery. “Disposal” includes landfilling and burning without energy recovery.

<sup>27</sup> Skovgaard, M., Andersen, F. M., Moll, S., and Larsen, H. (2005). "Outlook for waste and material flows - Baseline and alternative scenarios." European Topic Center on Waste and Material Flows, Copenhagen [http://waste.eionet.eu.int/publications/wp1\\_2005](http://waste.eionet.eu.int/publications/wp1_2005)

<sup>28</sup> Europe Environment Agency. (2003). “Europe’s Environment, the 3<sup>rd</sup> Assessment”. ‘Environment for Europe’ Ministerial Conference. Kiev.

<sup>29</sup> European Topic Center on Waste and Material Flows. (2004). "Waste and material flows 2004 - Current situation for Europe, Caucasus and Central Asia." Copenhagen.

<sup>30</sup> Stengler, E. (2005). "Waste to energy in Europe- Where are we and where are we going?" Proceedings of *The Future of Residual Waste Management in Europe*, Luxembourg.



The definition of MSW used to develop the statistics from Europe varies, but typically includes wastes from private households and wastes collected on behalf of local authorities from any source. MSW therefore includes a proportion of commercial and nonhazardous industrial waste as well as household wastes (collected waste, waste collected for recycling and composting, and waste deposited by householders at household waste disposal sites), household hazardous wastes, bulky wastes derived from households, street sweepings and litter, parks and garden wastes, wastes from institutions, commerce and offices. Generally, the European statistics do not include construction and demolition materials in the MSW accounting.<sup>31</sup>

Figure 9 shows per capita disposal amounts for the four largest counties in California (by population)<sup>32</sup>, the California statewide average, San Francisco City and County, New York City, the US average, several cities or regions in Western Europe and the Western Europe average. The California and US amounts were reduced by 30% to remove C&D and ‘special wastes’ in order to compare with European data.<sup>33</sup>

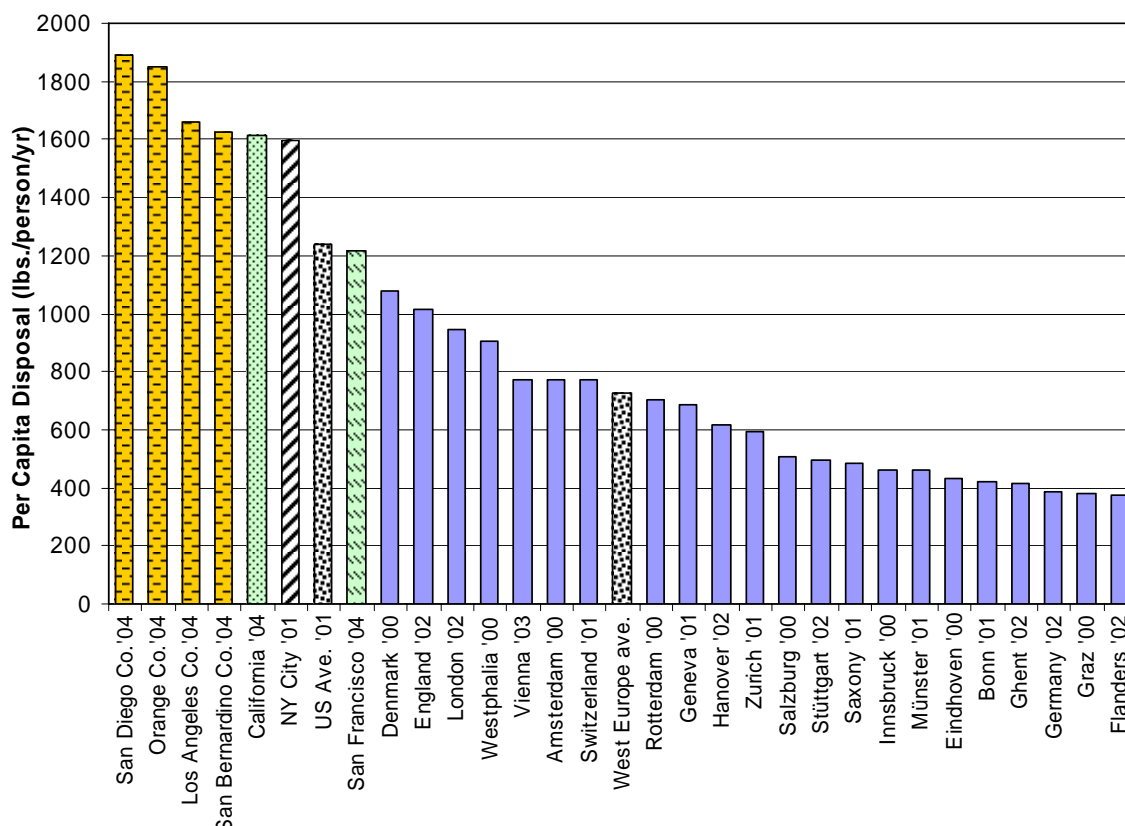
The per capita landfill disposal in Western Europe is about 730 lbs.  $\text{ca}^{-1} \text{y}^{-1}$ . The US average and San Francisco disposal are about 1240 lbs.  $\text{ca}^{-1} \text{y}^{-1}$ , the California and NY City averages are near 1600 lbs.  $\text{ca}^{-1} \text{y}^{-1}$  and the four largest counties have per capita disposals above 1600 lbs.  $\text{ca}^{-1} \text{y}^{-1}$ . The adjusted California per capita landfill disposal is a third more than the US average and more than twice that of Western Europe.

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<sup>31</sup> Europe Environment Agency. (2003). Op. Cit.

<sup>32</sup> Los Angeles, Orange, San Diego, and San Bernardino Counties

<sup>33</sup> 30% is the fraction of C&D and ‘special waste’ in California’s average waste stream (rounded up to 30%)



Note: California and US amounts reduced by 30% to remove C&D and 'special waste' for comparison with European data

Figure 9. Per-capita landfill disposal for US and Western Europe (sources <sup>34,35, 36, 37</sup>)

### Projections for Future Landfill Disposal

The Integrated Waste Management Board estimates remaining landfill capacity in the state is between 1.5 and 2.9 billion cubic yards<sup>38, 39</sup>. At approximately 0.6 ton per cubic yard, the capacity is between 900 and 1,700 million tons, which at the present rate of disposal (41 million tons per year) implies between 22 and 40 years of capacity.<sup>40</sup> However, some of the most populated regions in the state have less remaining landfill capacity, implying substantial future transportation requirements if local alternatives are not adopted.

<sup>34</sup> Strange, K. (2005). "European Strategy - Organics key to high diversion rates." BioCycle West Coast Conference, San Francisco.

<sup>35</sup> Goldstein, N., and Madtes, C. (2001). "The state of garbage in America." *Biocycle*, 42(12), 42-+.

<sup>36</sup> Themelis, N. J. (2003). "Analyzing data in state of garbage in America, EPA reports." *BioCycle*, 44(1), 22.

<sup>37</sup> CIWMB Disposal reporting system and Department of Finance demographic data

<sup>38</sup> CIWMB June 18, 2002 Board Meeting Agenda Item 74 background document. Available at; <http://www.ciwmb.ca.gov/agendas/mtgdocs/2002/02/00007304.doc>

<sup>39</sup> GeoSyntec Consultants. (2004). "Landfill Facility Compliance Study, Task 8 Report." Contractor's report to CIWMB. Publication #520-04-005. Available at; <http://www.ciwmb.ca.gov/Publications/Facilities/52004005.pdf>

<sup>40</sup> If disposal grows with population (~1.4 % y-1), then remaining capacity is 18 to 32 years. Rosario Marin, Former Chair of CIWMB indicated at a legislative hearing for AB 1090, 16 November, 2005, that permitted landfill capacity is about 35 years but only 18 years for currently active (or built) landfills.

Projections of future solid waste disposal amounts can be made by assuming either per capita disposal and population trends, or by using per capita generation, diversion, and population predictions. This is useful to illustrate the combined effects of population growth and changes in per capita disposal in order to understand magnitudes of waste reduction, increased recycling, or 'new uses' required in order to reduce annual landfill amounts to some future target. These kinds of projections can also provide insight into how significant measures will need to be in order to achieve 'zero waste'.<sup>41</sup>

Figure 10 shows historical California landfill amounts from 1990 as well as potential future scenarios through 2050. The scenarios assume a population growth rate of about 1.4%/year in the near term decreasing to about 0.6%/year by 2050.<sup>42, 43</sup> Each scenario is then created using different per capita waste disposal assumptions as follows:

- A) Present trend of **constant** per capita disposal depicted in Figure 8 continues (about 2200 lbs. per person per year).
- B) Decrease in per capita disposal of 1%/year (to 1400 lbs per person per year by 2050)
- C) Decrease in per capita disposal of 2%/year (to 880 lbs per person per year by 2050)
- D) Decrease in per capita disposal of 5%/year (to 200 lbs per person per year by 2050)
- X) **Increase** in per capita disposal of 1%/year (to **3500** lbs per person per year by 2050)

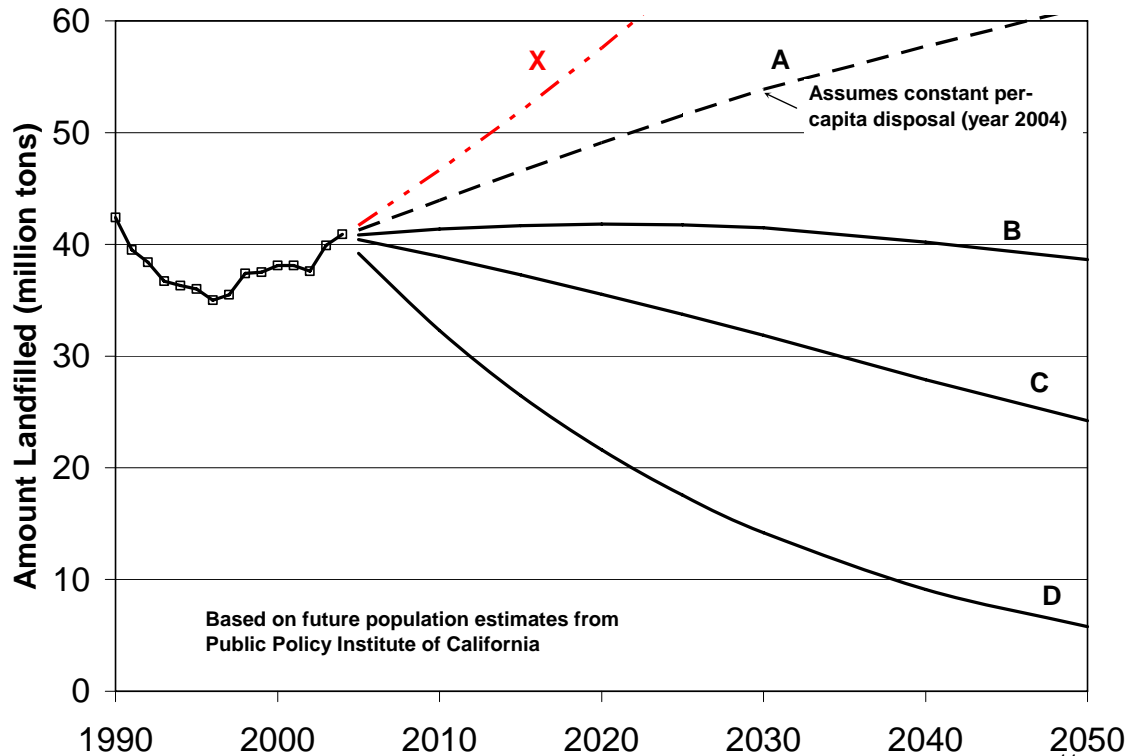


Figure 10. Historical and projected landfill amounts for California (Adapted from<sup>44</sup>)

<sup>41</sup> Where 'zero waste' is taken to mean 'no disposal to landfill'.

<sup>42</sup> State of California, Department of Finance, (2004). Population Projections by Race/Ethnicity, Gender and Age for California and Its Counties 2000-2050, Sacramento, California, May 2004.

<sup>43</sup> Hanak, E., and Baldassare, M. (2005). Op. Cit.

<sup>44</sup> Williams, R. B., and Jenkins, B. M. (2004). "Management and conversion of organic waste and biomass in California." 2nd World Conference and Technology Exhibition on Biomass for Energy, Industry and Climate Protection., Rome, Italy.

The combination of both population and increasing per capita disposal quickly drives disposal scenario X to high levels that will be quite burdensome to the disposal infrastructure.

Scenario A (using current per capita disposal) shows influence of population growth on California landfill disposal, all else being equal.

The annual reduction in per capita waste disposal modeled by B is too small to significantly reduce landfill amounts in the long term as population increases (scenario B effectively counters expected population growth). Scenario C decreases with time because per capita disposal declines faster than population growth. Scenario D might represent the path (viewed from the landfill disposal perspective) that a ‘zero waste’ initiative would pursue. The 5% per year reduction in per-person disposal modeled by D is quite drastic and not likely to be achieved without major societal changes (i.e. after 10 years of 5% per capita disposal reductions, the average individual would be disposing about 60% of the first year amount).

Jurisdictions meeting the 50% diversion have no further incentive to reduce the amount of landfilled material unless faced with the expense of opening new landfills or are driven by the community to reduce as a matter of principal. Market price for recyclable materials combined with the expense of recovery seem to be insufficient to utilize more of the biomass or plastics in the disposed solid waste stream.

There are several factors that may change the existing market including the implementation of a renewable portfolio standard (RPS) for electricity in the state and potential caps or reduction targets for greenhouse gas (GHG) emissions. Inadequate landfill capacity and increased costs of disposal can affect local and regional market conditions to favor more use of waste materials. There are several waste management jurisdictions in the State actively pursuing alternatives to landfill and increasing diversion beyond mandates because of limited landfill capacity or interest in local power production, including the recent RenewLA program, San Francisco and others.

Without additional policy measures or a large increase in recyclable commodity prices, it is not likely that reductions in material flowing to landfill will occur. An ‘additional policy measure’ that comes to mind is to simply increase the diversion rate mandate. However, before increasing the required diversion rate above the current 50% mandate, it would be useful to verify the accuracy of the accounting method used in California which hasn’t occurred since development of the adjustment method in 1994 using only one year of measured waste generation data. As discussed earlier, the fact that per-capita disposal in California has been constant for ten years, is a third higher than the US average (where many states pay much less attention to integrated waste management concepts), and is more than twice that of Western Europe diminishes confidence in the present waste generation and diversion estimating process in California (refer to figures 8 and 9).<sup>45</sup>

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<sup>45</sup> If diversion really is approaching 50%, why is so much recyclable material still being landfilled?

Even if the accuracy is found to be acceptable, there seems to be an inherent disincentive for waste reduction in the diversion requirement approach. With this approach, the waste generation estimate is used to set the upper disposal limit for a jurisdiction to be in compliance. The higher the estimated waste generation amount, the higher the allowable disposal.

In order to manage the affects of increased population and changes in economic status, reducing per capita disposal is a more direct approach, certainly measurable and is the only way to achieve a zero waste society. A combination of measures that might work to these ends include simply charging higher waste disposal fees, 'pay as you throw' fees, implementing extended producer responsibility (EPR) or 'producer pays' laws, restrict or reduce per capita disposal, and/or regulate total organic carbon (TOC) and/or bulk energy content of the material being landfilled. Another possible policy technique is to implement a landfill tonnage 'cap and trade' system (analogous to air pollution cap and trade schemes).

### **Landfill Disposal 'Cap and Trade'**

England has implemented a landfill 'cap and trade' scheme in order to meet the EU landfill directive targets for biodegradable waste. Called the 'Landfill Allowance Trading Scheme', it was implemented in April, 2005.<sup>46</sup> This is believed to be the first of its kind in the municipal waste sector.

Local waste authorities across England have been assigned landfill disposal allocations or 'allowances' for each year out to 2020. These 'landfill allowances' are tradable and are measured in tons of biodegradable material. A 'landfill allowance' market between waste jurisdictions has been established and trading is ongoing (trade prices so far aren't available to the public but trade and banking/borrowing quantities by jurisdiction can be viewed in the public register).<sup>47</sup>

Authorities can buy more allowances if they expect to landfill more than is permitted by the number of allowances they hold. Authorities with low landfill rates can sell their surplus allowances. Waste disposal authorities will also be able to save unused allowances (banking) or bring forward part of their future allocation (borrowing).

Jurisdictions that exceed the limit set by the allowances they hold will be fined £150 for every metric tonne they are over the limit.

A disposal 'cap and trade' system is an interesting idea and might work for California.

### **Conversion Technology and Landfill Disposal Reduction**

Figure 11 illustrates the effects of increased recycling and/or growth of a conversion technology industry overlaid with some of the scenarios from Figure 10 (shown here as dashed lines A, B, C). Curve NU (for 'New Use') simulates growth of conversion

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<sup>46</sup> <http://www.defra.gov.uk/environment/waste/localauth/lats/index.htm>

<sup>47</sup> See: <http://lats.defra.gov.uk/Default.aspx?Menu=register&Module=publicRegister/wdaRegister>

technology capacity at the rate of approximately 500,000 tons per year<sup>2</sup> (i.e., addition of three 175,000 ton capacity facilities each year starting in 2010).

This CT growth rate was chosen to simulate new disposal from projected population growth (i.e., its slope is roughly equivalent to the slope of scenario A

Thus, curve NU cancels the influence of population in scenario A when subtracted from scenario A and gives a stable annual landfill amount of about 40 million tons. Curves 'B-NU' and 'C-NU' show the effect of 'new use' of material combined with decreasing per capita waste disposal of 1% and 2% per year respectively (cases B and C in Figure 10). A combination of 'new use' of MSW with annual reductions in per capita waste disposal (curves B-NU and C-NU) will result in achieving net landfill disposal amounts between 3 and 17 million tons per year by 2050 (Figure 11).

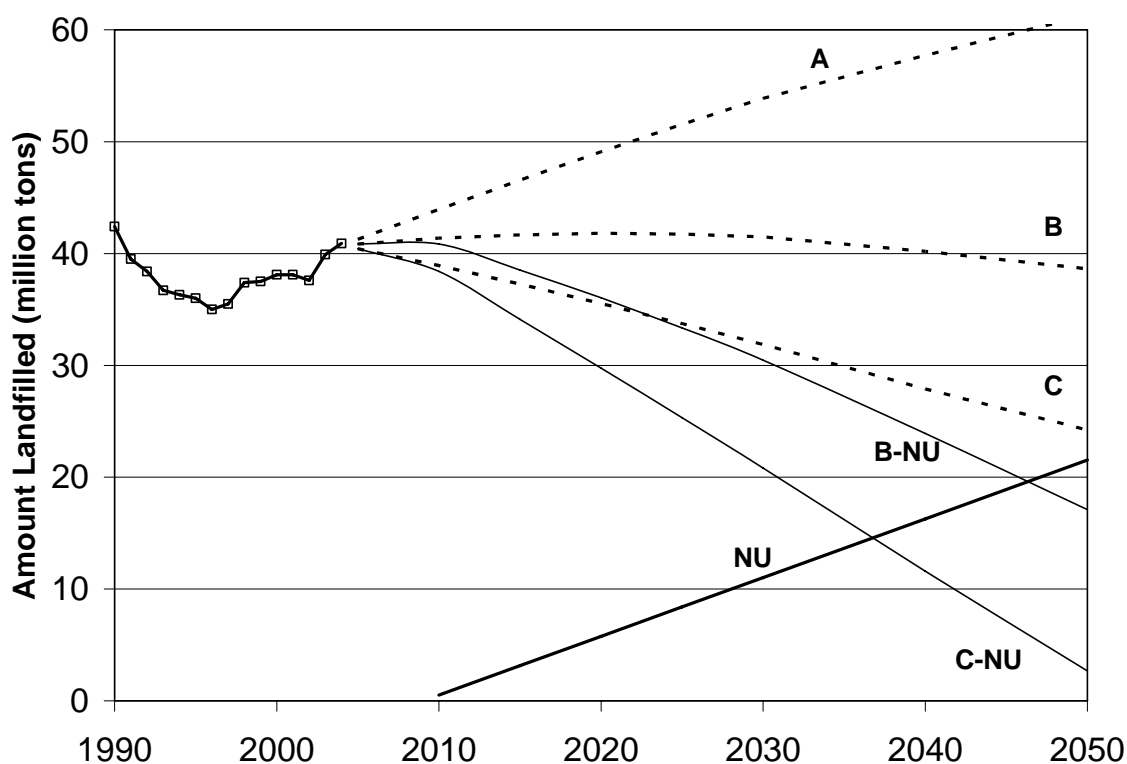


Figure 11. Historical and predicted landfill amounts including 'new use' of material (Source <sup>48</sup>)

### Conversion Technology Capacity to Offset Disposal Increases

If curve NU represented capacity of MSW conversion facilities for power, fuels, chemical feedstocks or other products, then required growth rate of capacity would average about 525,000 tons per year. At this rate, more than 90 facilities averaging 175,000 tons per year capacity would need to be operating by 2040 and converting some

<sup>48</sup> Williams, R. B., and Jenkins, B. M. (2004). Op. Cit.

16 million tons of post recycled MSW to offset expected population and waste disposal growth.

Policy measures can provide incentives to reduce landfill disposal, but need to be placed in a context of technical feasibility. However, barring policy and consumptive pattern changes, growing population and affluence will lead to sharply increased solid waste disposal amounts.

### **Status of Conversion Technology Investigation and Policy**

The existing market for organic material utilization is not sufficient to consume the state's production of organic waste. Furthermore, it has become evident that there are barriers to increased diversion of organic material that are not simply or wholly economic based. Among these barriers are certain statutory/regulatory restraints, and a lack of data on potential technologies and markets<sup>49</sup>. Recommendations for addressing the identified barriers resulted in legislation (Assembly Bill 2770, Chapter 740, Statutes of 2002), which, among other things, directed the CIWMB to research and evaluate new and emerging non-combustion thermal, chemical, and biological technologies, conduct an assessment on the potential impact of conversion technologies (CTs) on recycling markets, conduct a limited life cycle assessment (LCA) of specific technologies and submit a report to the Legislature.

With respect to California waste management, conversion technologies are those methods that do not employ full oxidative combustion (commonly called incineration) to treat post-recycled MSW that otherwise would be landfilled. These include thermochemical processes such as pyrolysis and gasification and biochemical processes such as aerobic and anaerobic digestion and fermentation.

For the most part, the various studies have been completed. In brief, the main conclusions from the limited LCA are;

- Conversion technologies can contribute more energy than landfilling and transformation (full oxidative combustion) due to greater conversion and higher efficiencies.
- Generally there are lower emissions of criteria air pollutants (including NO<sub>x</sub>, CO, PM, and SO<sub>x</sub>) from conversion technologies than from landfilling and transformation.
- There are reduced lifecycle greenhouse gas emissions.
- Conversion technologies would decrease the amount of waste disposed of in landfills.
- The environmental benefits of the hypothetical CT scenario are highly dependent upon the actual performance of the technologies including whether they can enhance materials recycling rates from pre- or post-processing.

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<sup>49</sup> See findings (Barriers and Recommendations) from May, 2001 'Conversion Technologies for Municipal Residuals' forum at: <http://www.ciwmb.ca.gov/Organics/Conversion/Events/TechForum00/>

Because there are essentially no facilities of this type in the US and only limited pilot projects in the US and Canada, there is a high level of uncertainty in the results. In addition, because data on emissions of toxic and hazardous substances from CTs are not widely available, adequate health risk assessments could not be done in the LCA

Conclusions from the market impact assessment include;

- It is expected that recycling of glass, metal, and plastic recycling would increase under the “base case” conversion technology scenarios
- The impact on paper recycling would be negligible with out a shift in prices for recycled paper
- Source-separated recyclables (paper and plastics) are not likely to flow to conversion technology facilities, based on pricing differentials
- Conversion technology facilities may negatively impact the ability of municipalities and private companies to increase recycling from currently untapped waste streams and generators, but the net affect of this is projected to be minimal

The detailed reports from these investigations are referenced below.<sup>50, 51, 52, 53,</sup>

Greater use of biomass in solid waste will also depend on future regulatory strategies, and in particular whether technologies are classified as transformation or not under the current waste management hierarchy. Under PRC 40201, transformation includes incineration, pyrolysis, distillation, and biological conversion other than composting. Gasification was removed from the transformation definition under Assembly Bill 2770 (2002), although the definition that was incorporated in statute is restrictive to the extent that few if any actual gasification systems could qualify..

An attempt was made to address some of these issues through Assembly Bill 1090 introduced in 2005. An informational hearing on the draft bill was held by the Assembly Natural Resources Committee in November 2005, but a hearing on the bill scheduled for 9 January 2006 was canceled and the bill is no longer active. A new bill has been introduced (AB 2118, Matthews).

The issues addressed by AB 1090 raise a larger question as to whether the present approach to waste management in the state is adequate as advanced conversion technologies continue to be developed and implemented. Questions also arise as to whether materials now considered waste and regulated under the Integrated Waste Management Act and Board should continue under such management if they instead

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<sup>50</sup> (2005) Conversion Technologies Report to the Legislature. CIWMB Staff Report; [www.ciwmb.ca.gov/agendas/mtgdocs/2005/05/00018517.doc](http://www.ciwmb.ca.gov/agendas/mtgdocs/2005/05/00018517.doc)

<sup>51</sup> (2004) Draft UC Report on Evaluation of Conversion Technology for CIWMB (plus appendices); <http://biomass.ucdavis.edu/pages/reports.html>

<sup>52</sup> “Solid Waste Conversion- A review and database of current and emerging technologies.” Final Report. CIWMB contract IWM-C0172, (2003); <http://biomass.ucdavis.edu/pages/reports.html>

<sup>53</sup> Life Cycle and Market Impact Assessment of Noncombustion Waste Conversion Technologies. (2004). Contractor's Report to the CIWMB. Prepared by: RTI International, National Renewable Energy Laboratory, Hilton Farnkopf & Hobson, and Boisson & Associates, July 2004. Available at: <http://www.ciwmb.ca.gov/agendas/mtgdocs/2004/09/00016979.doc>



serve as resource feedstocks for industrial processes, such as energy conversion. It seems likely that the material (though not necessarily CT facilities) will continue to require CIWMB regulation unless and until exempted by legislation. The structure of waste regulation, including retention of a transformation category, is likely to experience increasing revision in the future.

### **Need for Comprehensive LCA**

In the U.S. and California, one of the primary issues preventing the expansion of MSW incineration facilities or conversion technologies is the perception of high levels of hazardous air emissions from these types of facilities. This has led to a high degree of skepticism among environmental and environmental justice groups with regard to claims made in project proposals for waste conversion systems, especially thermochemical conversion technologies. Another primary concern is the fear by some that current and future material destined for recycling and composting will instead divert to conversion.

The US and especially Europe and Japan have made large improvements in the environmental performance of solid waste combustion and other systems. For example, the US MSW combustion industry has reduced total dioxin emissions by more than 99% (compared to 1987) while increasing the amount of material consumed. Properly designed and operated combustion facilities can be considered ‘dioxin sinks’ because the sum of emissions (air, solid, and liquid) from newer facilities is lower than the amount of dioxin present in the feedstock (which is due to dioxin in the background environment from human caused and natural combustion processes).<sup>54,55,56,57</sup> LCA studies of waste management scenarios that take into account hazardous emissions and health risks (as well as energy and greenhouse gas impacts) generally find standard dry-tomb sanitary landfilling to be the poorest performing management technique, followed by open air (windrow) composting. Modern combustion facilities and anaerobic digestion with controlled emission composting of digestate seem to fare the best in these LCA studies (see discussion below).

Policy makers are currently struggling with definitions, assumptions, and decisions that are nearing 20 years old (referring to AB 939). Legacy assumptions about ‘highest and best use’ may no longer be correct as solid waste disposal continues to grow.

To address ‘highest and best use’ questions (and possibly to reaffirm legacy decisions), a comprehensive LCA of integrated waste management in California should be done as a follow on to the partial LCA study the Legislature directed the Waste Board to do. A comprehensive LCA must include the full range of waste management techniques and

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<sup>54</sup> (2004) Draft UC Conversion Technology Report. Op. Cit.

<sup>55</sup> Anderson, D. R., and Fisher, R. (2002). "Sources of dioxins in the United Kingdom: the steel industry and other sources." *Chemosphere*, 46(3), 371-381.

<sup>56</sup> Porteous, A. (2005). "Why energy from waste incineration is an essential component of environmentally responsible waste management." *Waste Management*, 25(4), 451-459.

<sup>57</sup> Porteous, A. (2001). "Energy from waste incineration - a state of the art emissions review with an emphasis on public acceptability." *Applied Energy*, 70(2), 157-167.

strategies including composting and the various conventional recycling methods (including emissions and conditions of recycling processes overseas that receive California waste).

### **Improvements in solid waste combustion emissions**

Chlorinated organic compounds emissions, especially polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F), have been linked to combustion of MSW. In the late 1980s, combustion of MSW was listed as the leading source of dioxin emissions in the country (approximately 60% of total). Maximum available control technology (MACT) regulations promulgated by the EPA in 1995 forced the industry to retrofit with better emission control technologies where possible and shut down facilities that could not be improved by 2000. Today, the level of dioxin air emissions from combustion of MSW in all large facilities (>250 tons of waste per day) in the U.S. has decreased from 8900 g toxic equivalent (TEQ) per year in 1987 to 12 g TEQ per year by 2000, a decrease of 99.9%.<sup>58</sup> During this period, the number of operating facilities increased and the amount of waste burned nearly doubled from 15 million to about 28 million tons per year (TPY). US dioxin emissions to the atmosphere from all sources have decreased by an order of magnitude from 14,000 g TEQ per year to 1100 g TEQ per year. Solid waste combustion is now responsible for only 1 % of U.S. dioxin air emissions. Figure 12 gives an inventory of dioxin air emissions in the U.S. by source type. Also shown in the figure are expected dioxin emissions if all California solid waste that is currently going to landfill were combusted with the same emission factor as the Stanislaus Covanta mass burn facility near Crows Landing, California. This emission value of 10 g TEQ for 40 Mt of California waste is lower than the current US MSW combustion dioxin emission from only 28 Mt because the Stanislaus facility has a lower emission factor than the US average.<sup>59</sup>

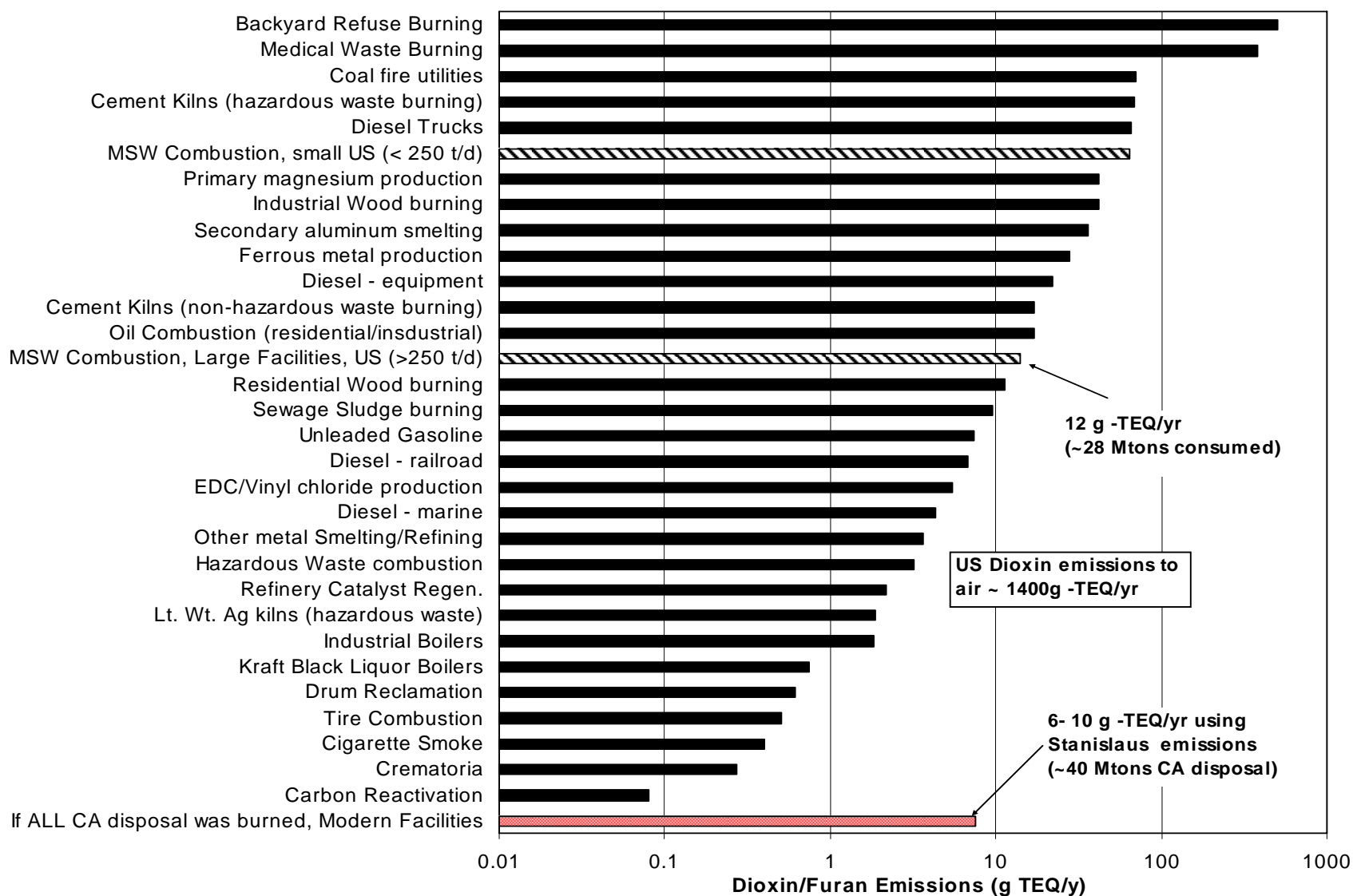
In addition, dioxin emissions have been measured in exhaust from LFG flares and energy facilities.<sup>60</sup> Figure 13 shows dioxin emission concentrations for several waste management technologies, including the three California MSW combustion facilities, a pilot project in southern California that pyrolyzes waste feedstock (IES Romoland) and several LFG flares or engine facilities. California and European emission limits are shown (corrected to 7% oxygen). The averages of the facilities shown are each below the strict European limit, though some of the individual test results for two LFG applications and the IES Romoland facility exceeded the European limit (while remaining below the California limits). The IES Romoland facility is in a start-up/research phase and will likely have lower emissions after best operational practices are developed for the facility.

<sup>58</sup> US EPA Docket A-90-45, VIII. B.11 and USEPA Dioxin source Inventory 2002. (Can be accessed at <<http://cfpub.epa.gov/ncea/cfm/recorddisplay.cfm?deid=20797>>).

<sup>59</sup> See: 'Emissions from Large Municipal Waste Combustion Units (MWCs) Following MACT Retrofit' (Year 2000 Test Data), USEPA Document ID OAR-2003-0072-0013

<sup>60</sup> Caponi, Frank R., Ed Wheelless & David Frediani. 1998. "Dioxin and Furan Emissions From Landfill Gas-Fired Combustion Units," County Sanitation Districts of Los Angeles County, 98-RP105A.03, 1955 Workman Mill Rd. Whittier, CA 90607

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Adapted from 'Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States: The Year 2000 Update (External Review Draft, March 2005; EPA/600/p-03/002A)', [http://www.epa.gov/ncea/pdfs/dioxin/2k-update/pdfs/Dioxin\\_Chapter\\_1.pdf](http://www.epa.gov/ncea/pdfs/dioxin/2k-update/pdfs/Dioxin_Chapter_1.pdf)

Figure 12. US dioxin emission inventory by source type

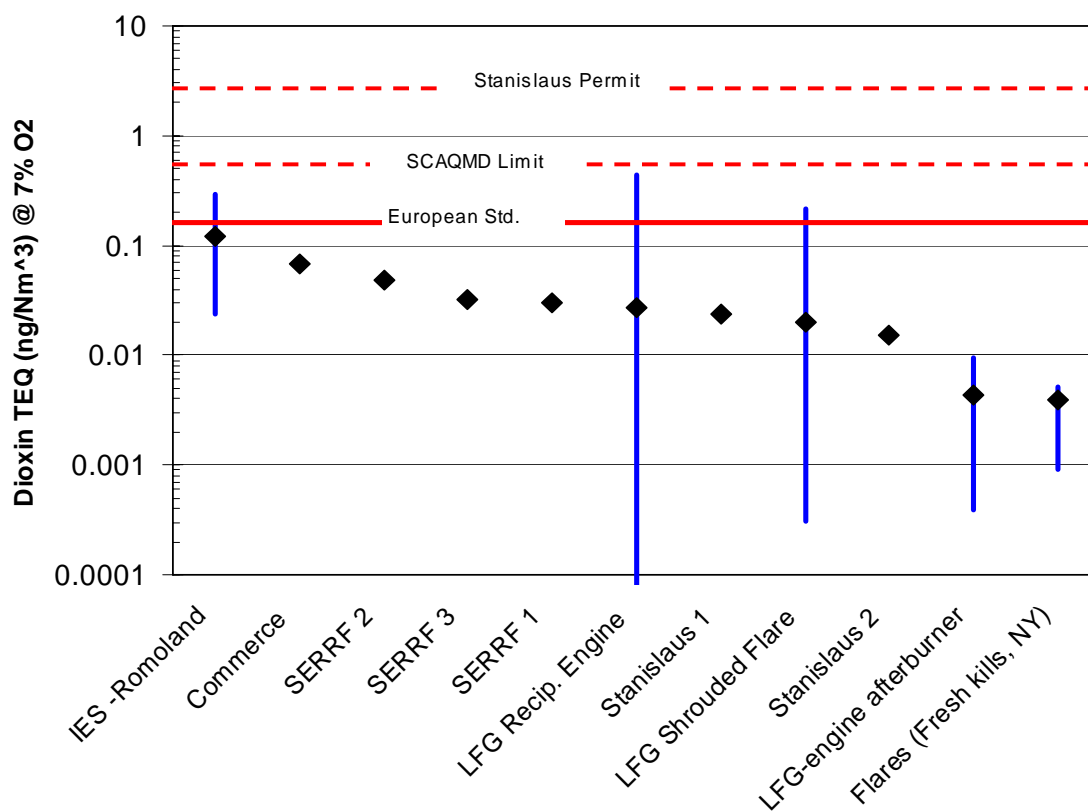


Figure 13. Dioxin emission concentrations for several technology types <sup>61,62, 63</sup>

Figure 14 displays dioxin emissions per ton of material consumed (emission factors) for US, California and European waste combustion facilities, the pilot pyrolysis facility in California (IES Romoland), and a pyrolysis/gasification in Chiba Japan (which uses a Thermoselect conversion unit and fires the synthesis gas in Jenbacher reciprocating engines). Also shown in Figure 14 b are dioxin emissions from landfill gas combustion per ton of waste-in-place (WIP) at the landfill (a quasi emission factor).

<sup>61</sup> Caponi, Frank R., Ed Wheless & David Frediani. 1998. "Dioxin and Furan Emissions From Landfill Gas-Fired Combustion Units," County Sanitation Districts of Los Angeles County, 98-RP105A.03, 1955 Workman Mill Rd. Whittier, CA 90607

<sup>62</sup> IES Romoland June 2005 source test report. Professional Environmental Services, Inc., Job 1065.001

<sup>63</sup> Emissions from Large Municipal Waste Combustion Units (MWCs) Following MACT Retrofit (Year 2000 Test Data), USEPA Document ID OAR-2003-0072-0013

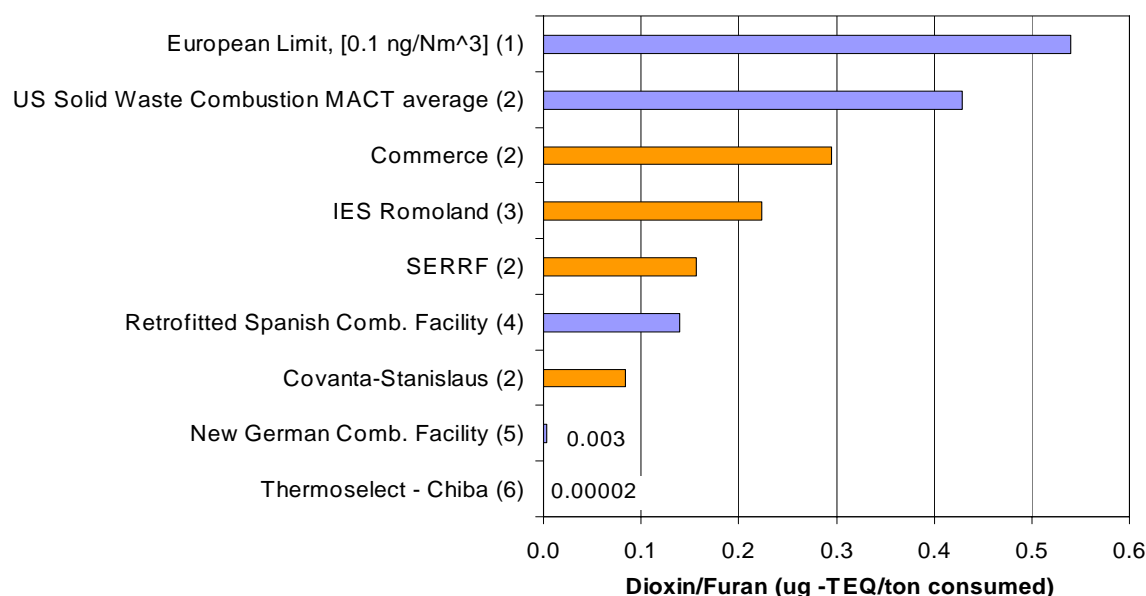


Figure 14. Dioxin emissions from conversion of MSW\*

\*All units employ solid waste combustion except IES Romoland and Thermoselect - Chiba

Notes and Sources:

- 1)\* assume 0.1 ng TEQ/NM<sup>3</sup> (11% O<sub>2</sub>) and 6000 Nm<sup>3</sup>/tonne
- 2)Emissions from Large Municipal Waste Combustion Unties (MWCs) Following MACT Retrofit (Year 2000 Test Data), USEPA Document ID OAR-2003-0072-0013
- 3)IES Romoland June 2005 source test report. Professional Environmental Services, Inc., Job 1065.001
- 4)Abad, E., Adrados, M. A., Caixach, J., and Rivera, J. (2002). "Dioxin abatement strategies and mass balance at a municipal waste management plant." Environmental Science & Technology, 36(1), 92-99.
- 5)MVR Environmental Statement (2005) [http://www.mvr-hh.de/eng/elemente/pdfs/MVR\\_UW\\_2005\\_eng.pdf](http://www.mvr-hh.de/eng/elemente/pdfs/MVR_UW_2005_eng.pdf)
- 6)Yamada, S., Shimizu, M., and Miyoshi, F. (2004). "Thermoselect waste gasification and reforming process." Technical Report No. 3 (July), JFE Group, Japan. [Exhaust from reciprocating engine]

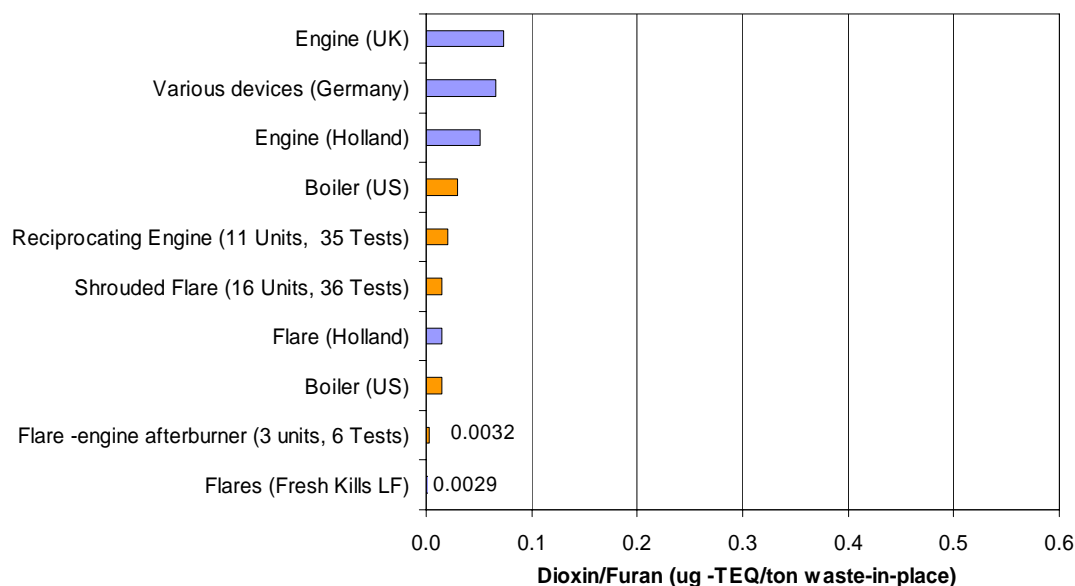


Figure 14 b Dioxin emissions per ton of WIP from combustion of landfill gas

## Results from LCA of waste management scenarios

Two recent papers that discuss LCA results for solid waste management scenarios were reviewed. One study compared results from four LCA methods for Korean mixed solid waste and practices with landfilling being the business as usual case.<sup>64</sup> The other study compared several current European solid waste treatment practices using a single LCA methodology.<sup>65</sup> The functional unit of waste in the Korean study by Seo was one ton of the complete mixed MSW stream whereas the Edelmann study used 10,000 tons of source separated household and yard waste (biogenic fraction of solid waste). The Edelmann study does not consider landfilling untreated biogenic solid waste in the LCA because the practice is banned in many countries of the EU and will likely be banned through out the EU in the future.

For the study in Korea by Seo, landfilling (with no LFG recovery) has the highest life-cycle environmental impact with combustion and anaerobic digestion (both with energy recovery) having the lowest (See Figure 15). Open composting consistently ranked second highest in lifetime impacts.<sup>66</sup>

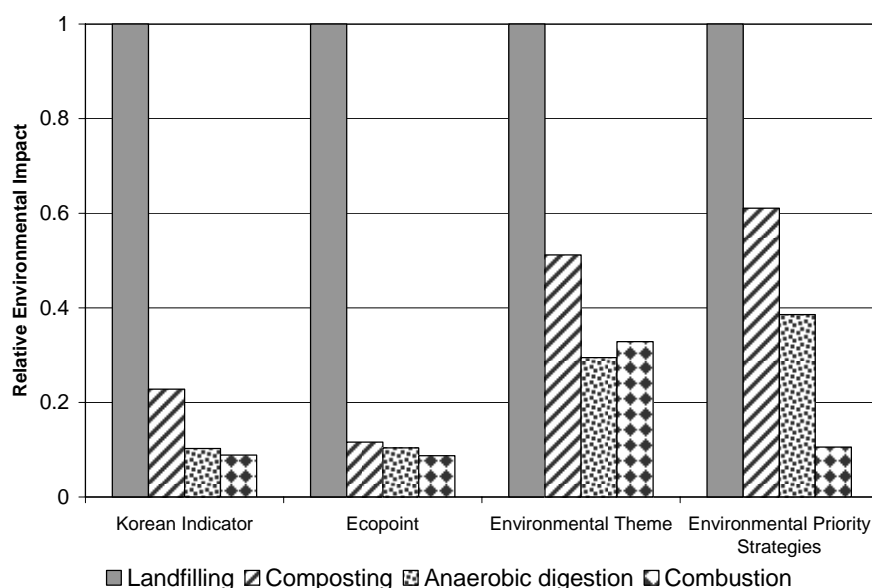


Figure 15. Results from four LCA methodologies (or LCIA for life cycle impact assessment) used to compare solid waste management scenarios in Korea (adapted from Seo, et al. (2004)).

<sup>64</sup> Seo, S., Aramaki, T., Hwang, Y. W., and Hanaki, K. (2004). "Environmental impact of solid waste treatment methods in Korea." *Journal of Environmental Engineering-ASCE*, 130(1), 81-89.

<sup>65</sup> Edelmann, W., Baier, U., and Engeli, H. (2004). "Environmental aspects of the anaerobic digestion of the organic fraction of municipal solid wastes and of agricultural wastes." *10th World Congress on Anaerobic Digestion*. Montreal, Canada.

<sup>66</sup> See below about cautions making comparisons to California facilities.

Impacts are based on equal amounts of 'standard' Korean solid waste treated in one of four ways, 1) dry-tomb landfill with no collection of landfill gas, 2) composting with stabilized residue sent to landfill, 3) anaerobic digestion with energy recovery and stabilized residue sent to landfill, and 4) combustion with energy recovery and residue landfilled.

Environmental impact categories considered in the analyses were;

- Human toxicity to air emission
- Photochemical oxidant creation
- Ecotoxicity to water emission
- Global warming
- Stratospheric ozone depletion
- Acidification
- Eutrophication
- Abiotic resource depletion

In each case, landfilling had the highest negative environmental impact due largely to global warming contribution (methane emissions) and water quality (toxicity and eutrophication affects). Averaging the results from the four LCA methods, the landfill treatment method had 3 times the negative environmental impact as open composting, the method with the next highest impact. Recovery of LFG and energy production in the landfill scenario would reduce the negative impacts but would likely still be larger than the compost scenario.

In this analysis, composting has high impacts due to the relatively large amount of energy required for the process, some emissions of VOCs (including some methane created in 'anaerobic pockets' of compost) and its affect on leachate after being landfilled. Using the compost in land application or soil amendment instead of putting in the landfill would likely reduce its overall impact.

Combustion with energy recovery ranked lowest in environmental impact in 3 of the 4 methodologies with one method ranking it slightly poorer than anaerobic digestion with energy recovery. Anaerobic digestion with energy recovery and landfilling of the solid residue had very good overall environmental impacts in the study. It was ranked second lowest (in negative impacts) in 3 methods and lowest by one of the methods.

Caution should be used in generalizing these results for application in California. At least two important management practice differences in are likely to be used in California; LFG would be recovered and flared or converted to energy, and some or all composted material would not go to landfill.

The study by Edelman et al., (2004) used operating data from full size commercial composting and anaerobic digestion facilities in Switzerland. The data for the combustion case was based on design data from the most recent facility being commissioned in Switzerland. The LCA method used was EcoIndicator99 and

incorporated more than 100 impact factors (materials and resource inputs and emissions). The impact categories were;

Human toxicity to air emission  
 Photochemical oxidant creation  
 Carcinogens  
 Ecotoxicity to water emission  
 Global warming  
 Stratospheric ozone depletion  
 Acidification  
 Eutrophication  
 Heavy metals  
 Pesticides

The options evaluated included combustion with energy recovery, anaerobic digestion with energy recovery followed by aerobic stabilization of the digestate, and open composting with periodic windrow turning. The stabilized digestate and compost product were assumed to be land applied.

Figure 16 shows the relative environmental impact of three treatment options for the biogenic portion of solid waste. Open composting and combustion were nearly equal in terms of environmental impact (note that landfilling untreated biogenic waste was not evaluated because it is generally no longer practiced in much of Europe). Anaerobic digestion had the lowest life cycle impact. Because the stabilized solid residuals from the two biochemical treatment types (open composting and AD) were land applied, then the relative impacts of the three treatment methods in the Edelmann study are more applicable to comparing to California for source separated biogenic fraction of household and yard wastes.

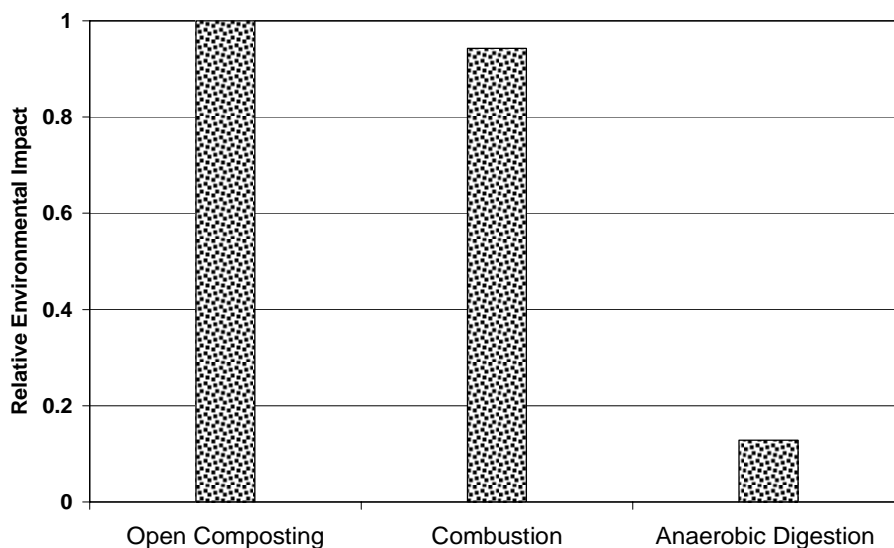


Figure 16. Relative impact from treatment options for biogenic wastes for a scenario in Europe (adapted from Edelmann et al. (2004))



## **MSW and the California RPS**

The RPS requires investor owned electricity utilities in California to provide a renewable energy content of 20% by 2017 (or 2010 on an accelerated schedule) which may provide some incentive statewide to utilize more MSW biomass in power production (plastics and other fossil derived compounds in MSW are not renewable sources).

The Energy Commission's Renewable Portfolio Standard Eligibility Guidebook defines acceptable renewable electricity sources for the purpose of use by the investor owned utilities (IOUs) when complying with the state's RPS requirements.<sup>67</sup>

The Commission has taken a generally fuel/energy-source based approach, rather than technology for determining the eligibility of produced electricity for renewable status. For example, power from solar, wind, small hydro, and conversion of purpose grown and/or woody biomass to power are all considered renewable electricity. Power derived from facilities that co-fire biomass with traditional fossil fuels (e.g., coal, oil, natural gas) can receive renewable credit for the portion of power produced by the renewable fuel source (biomass). There is even recognition that if and when hydrogen becomes a fuel for power that "only eligible RPS fuel stock may be used to produce hydrogen for use at an RPS eligible facility".

However, with respect to MSW as a fuel stock, the Commission defers to the conversion technology definition and does not consider the fossil energy content in the MSW fuel stock.<sup>68,69</sup> This contradicts the Commission's intent to base eligibility on renewable content in the fuel stock (rather than a technology) as well as ignores the Commission definitions for "renewable resources" and "fossil fuel".<sup>70</sup>

The renewable or biogenic component of the average California landfilled waste stream is about 60-65% on an energy basis with the remaining 35-40% from fossil derived material (see Table 1). However, CT facilities are likely to not use the complete post-recycled mixed waste stream (as described in Table 1) as a feedstock. Depending on the local waste stream, economics, and the requirements of the facility, the actual feedstock converted at a specific facility could range from 100% biogenic (renewable) components (e.g., non-recyclable paper and/or food and yard wastes) to nearly 100% non-renewable fossil fuel based components (such as a plastics rich stream chosen for its high energy content for production of fuels and electricity).

Since MSW conversion facilities will be individually permitted, the character of the feedstock will be fairly well characterized. It would be a simple matter to document in the permit process the proportion of electrical generation capacity that is attributable to renewable components of the waste stream (if any). Energy from facilities that convert

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<sup>67</sup> Raitt, H. (2005). "Renewables Portfolio Standard Eligibility Guidebook - Draft." *CEC-300-2005-028-SD*, California Energy Commission. Available at; <http://www.energy.ca.gov/2005publications/CEC-300-2005-028/CEC-300-2005-028-SD.PDF>

<sup>68</sup> Ibid.

<sup>69</sup> CT defined in Public Resources Code Section 25741(a)(3):

<sup>70</sup> See: <http://energy.ca.gov/glossary/>

waste tires only, should be considered renewable to the extent that natural rubber or latex is used in the tire composition (on the order of 15% in automobile tires).

Energy conversion can be a viable and perhaps profitable option for use of the solid waste stream. However, it should only be labeled 'renewable energy' to the extent that the fuel is derived from renewable components.

Greater use of biomass in solid waste will also depend on future regulatory strategies, and in particular whether technologies are classified as transformation or not under the current waste management hierarchy.

### **Consideration of MSW as a renewable resource in Europe**

In order to reduce green house gas emissions in attempts to comply with the Kyoto Protocol, the European Union is implementing strategies which include increased use of energy produced from renewable sources. The European Community Directive 2001/77/EC (27 September 2001)<sup>71</sup> contains definitions for renewable electrical energy sources:

DIRECTIVE 2001/77/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market

#### Article 2

##### **Definitions**

(a) 'renewable energy sources' shall mean renewable non-fossil energy sources (wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases);

(b) 'biomass' shall mean the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste;

The EC Directive includes in the definition of biomass- "the biodegradable fraction of industrial and municipal waste," although this definition appears overly restrictive depending in turn on the definition of "biodegradable" that may discount some fraction of biomass. The Directive also advises that of the electricity produced by facilities that consume both renewable and non-renewable feedstocks (mixed MSW), only that portion attributable to the renewable energy source is considered renewable electricity.<sup>72</sup> Electricity and heat from the organic portion of MSW is considered renewable in The

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<sup>71</sup> Directive 2001/77/EC (27 September 2001). Article 2(b).

[http://europa.eu.int/eur-lex/pri/en/oj/dat/2001/l\\_283/l\\_28320011027en00330040.pdf](http://europa.eu.int/eur-lex/pri/en/oj/dat/2001/l_283/l_28320011027en00330040.pdf)

<sup>72</sup> Ibid. Article 2(c).

Netherlands<sup>73</sup> and Switzerland. Currently, that fraction in Switzerland is 50%, based on a recent feedstock characterization for MSW combustion facilities.<sup>74</sup>

## **Discussion**

### **Policies**

California waste jurisdictions meeting the statutory 50% diversion requirement have no further incentive to reduce the amount of landfilled material unless faced with the expense of opening new landfills or are driven by the community to reduce as a matter of principle.

There are several factors that may change the existing market including the renewable portfolio standard (RPS) for electricity in the state and possible GHG reduction measures being discussed by the Governor as well as in the legislature.

The RPS requires investor owned electricity utilities in California to provide a renewable energy content of 20% by 2017 which may provide some incentive statewide to utilize more MSW biomass in power production. There are also efforts to accelerate the adoption of renewable energy and to increase the target share. Inadequate landfill capacity and increased costs of disposal can affect local and regional market conditions to favor more use of waste materials. There are several waste management jurisdictions in the State actively pursuing alternatives to landfill because of limited landfill capacity or interest in local power production.

Without additional policy measures, it is not likely that reductions in material flowing to landfill will occur. A combination of measures that might work to these ends include simply charging higher waste disposal fees, 'pay as you throw' fees, implementing extended producer responsibility (EPR) or 'producer pays' laws, restrict or reduce per capita disposal, and/or regulate total organic carbon (TOC) and/or bulk energy content of the material being landfilled. Another possible policy technique is to implement a landfill tonnage 'cap and trade' system (analogous to air pollution cap and trade schemes and has been implemented in England for MSW).

Increasing waste disposal fees may be effective but there are drawbacks. Incidence of illegal dumping would be expected to increase with higher disposal fees, especially in suburban and rural areas. This depends on how each waste generator, (residential or commercial) is charged for service (e.g., flat fee or per bin).

Implementing EPR laws in California and the US similar to those in the EU, at least for packaging material, could be quite effective. In the US, solid waste due to packaging and containers accounts for 32% of all municipal solid waste (MSW) generated and 28% of

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<sup>73</sup>Junginger, M., Agterbosch, S., Faaij, A., and Turkenburg, W. (2004). "Renewable electricity in the Netherlands." *Energy Policy*, 32(9), 1053-1073.

<sup>74</sup> Ludwig, C. personal communication. 9 October 2003

that disposed.<sup>75</sup> The German Packaging Ordinance implemented in 1991 appears to be successful and could be a useful model. In Germany, manufactures and distributors of consumer products are required to recover an amount of material equivalent to that contained in their products' packaging. Individual companies can recover the material themselves, or they can contract with the central recovery company established by the ordinance (Duales System Deutschland AG) which receives a package recovery fee from manufactures based on amount and type of packaging. The manufacturer can pass the fee along to consumers with higher prices, but there is now incentive to reduce costs through reduced packaging. From implementation in 1991 through 1997, the use of packaging declined from 95 to 82 kg ca<sup>-1</sup> y<sup>-1</sup>. Ninety percent of packaging material is recovered and 80% of that amount is recycled or converted in energy facilities. Consumers pay an average of US\$2.25 month<sup>-1</sup> in higher prices due to the package recovery fee.<sup>76</sup> If a packaging EPR policy were as successful in California as it has been in Germany (i.e., 90% recovery, 80% recycled) it would reduce the existing landfill stream by 20% or 9 million tons.

Other progressive waste management policies in the EU have evolved from Kyoto Protocol greenhouse gas reduction goals (includes requirements for increased renewable energy and decreases in CH<sub>4</sub> emissions from landfills) and are creating strong incentives for landfill alternatives. Another example from Germany is the requirement that for material being landfilled, the biogenic carbon (total organic carbon, or TOC) and chemical energy content must be less than 18% and 6 MJ kg<sup>-1</sup> respectively (California average disposed MSW stream has an energy content (HHV) of  $\approx$  5900 Btu/dry lb. (Table 1)).<sup>77</sup> If the California disposed solid waste stream were required to meet a 6 MJ kg<sup>-1</sup> energetic content (HHV), then removal of large amounts of biomass and plastics material would be necessary. If the energy containing components of the current waste stream (Table I) were reduced equally to leave a resulting mixture meeting the 6 MJ kg<sup>-1</sup> level, a reduction by 80% of the biomass and plastics would be required. This is equivalent to a 25 million ton (63%) reduction in the overall stream.

## Conclusions and Recommendations

California has significantly advanced the recycling, compost, mulch and waste disposal information reporting infrastructure since implementing AB 939 in 1990. However, total and per capita waste disposal have been flat or are increasing, which combined with a growing population in California increasingly burdens the environment and waste disposal systems. Policies and technologies that can reduce per capita waste disposal should be implemented in place of a diversion based approach which is difficult to measure and does not naturally create incentives for reducing waste generation.

Whether or not significant waste source reduction is implemented in California, very large waste streams are anticipated for at least the next 40 years. New uses and markets for the material currently landfilled (the post recycled waste stream) should be developed.

<sup>75</sup> USEPA Office of Solid Waste and Emergency Response, Municipal Solid Waste in The United States: 2001 Facts and Figures. Washington, DC, EPA530-R-03-011, (2003).

<sup>76</sup> The Green Dot - Duales System Deutschland AG <http://www.gruener-punkt.de/> (Accessed 30 April, 2004).

<sup>77</sup> Ludwig, C., Hellweg, S., and Stucki, S., Eds. Municipal Solid Waste Management-Strategies and Technologies for Sustainable Solutions. Berlin, Springer-Verlag, (2003) 130.

Energy and solid waste policies in Europe have advanced the state of technology for waste management and conversion. There are potential opportunities to adapt these policies and advanced systems in Europe to the emerging market in California, and further analysis of their impacts is needed.

The California Integrated Waste Management Board (CIWMB) is evaluating technologies suitable for converting components of MSW to power, fuels, chemicals, and other products as part of recently enacted legislation.<sup>78</sup> Though there are three existing MSW combustion facilities in California, construction of new single stage combustion facilities (incinerators) for MSW is likely to face strong opposition from some stakeholders. Additionally, current law discourages new facilities of this type because the material they consume will not be credited to the diversion component of the solid waste accounting (i.e., it will be treated as disposal and so loses any value associated with diversion status).

Greater use of biomass in solid waste will also depend on future regulatory strategies, and in particular whether technologies are classified as transformation or not under the current waste management hierarchy. These issues seek at least partial resolution through Assembly Bill 1090 introduced in 2005. The issues addressed by AB 1090 raise a larger question as to whether the present approach to waste management in the state is adequate as advanced conversion technologies continue to be developed and implemented. Questions also arise as to whether materials now considered waste and managed under the Integrated Waste Management Act and Board should continue under such management if they instead serve as resource feedstocks for industrial processes, such as energy conversion. The structure of waste regulation, including retention of a transformation category, is likely to experience increasing revision in the future.

Some jurisdictions in California that are currently investigating alternatives to standard landfill practices are meeting public resistance. Resistance is strongest to thermochemical processes with perhaps less resistance offered against biochemical processes. The resistance to thermal conversion seems to be based on the poor reputation earned by the solid waste combustion industry in the 1970s and earlier. The current state of the art is much improved and the surviving solid waste combustion facilities are emitting extremely low criteria and hazardous pollutants. Prescriptive definitions and regulations, such as that adopted under AB 2770 for gasification, may prove more proscriptive and reduce innovation in development of new approaches to waste management. Further consideration needs to be given to future strategies and whether performance based regulations might equally or better achieve state environmental, health, and resource objectives.

The potential for significant reduction in landfill disposal and use or conversion of materials currently being disposed is possible with an integrated approach that reduces waste production and increases new use of waste material and waste conversion will have an important role.

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<sup>78</sup> Matthews, AB 2770 (Statutes of 2002), [http://www.leginfo.ca.gov/pub/01-02/bill/asm/ab\\_2751-2800/ab\\_2770\\_bill\\_20020920\\_chaptered.html](http://www.leginfo.ca.gov/pub/01-02/bill/asm/ab_2751-2800/ab_2770_bill_20020920_chaptered.html).

## Appendix

### Potential energy calculation notes:

Potential primary energy estimates were made by simply multiplying the appropriate material energy content on a per weight basis (HHV) by the amount of that material available. This is done for each component in the waste stream.

For estimating the amount of electrical generation capacity that could be developed from the current disposed waste stream, it was assumed that the stream would be divided based on moisture content. The high moisture components are perhaps most appropriately converted through biochemical systems (anaerobic digestion, for example). Though anaerobic digestion (AD) is suitable for high moisture feedstocks, a major disadvantage of AD is that conversion is incomplete; some 50% of the organic material is not converted. Lignin and other recalcitrant organics are not converted and remain as residue for composting<sup>79</sup> or landfill. The aerobic processing of digester sludge through composting can further reduce volume, but anaerobic conditions maintained in most landfills may not reduce volume except over very long periods of time. If only the produced biogas is converted to electricity (no energy production from the digestate), this process has an overall energy conversion efficiency (electrical energy out/waste stream energy in) of about 10% or less.

The lower moisture components are assumed to be converted by thermal means (gasification, pyrolysis, or combustion). The energy and/or heat in the product gases can be used in a boiler to run a steam cycle<sup>80</sup> or the gases (from a gasifier or pyrolyzer) can run a gas engine or turbine for electricity production. These methods have overall energy efficiencies of electrical generation of 20-25%. The Table 1 estimate uses 20% for thermal conversion to electricity efficiency (Biomass integrated gasifier combined cycles<sup>81</sup>, BIGCC, have projected electrical conversion

<sup>79</sup> Composting may or may not degrade these components further.

<sup>80</sup> The Rankine vapor power cycle is the most widely used thermal cycle for electrical power generation throughout the world. It is commonly called a 'steam cycle' when the working fluid is water. It consists of a boiler where heat is added to liquid phase pressurized working fluid (water) to create a high temperature and pressurized vapor (steam if the working fluid is water). The high pressure steam is expanded across a turbine which turns a generator creating electrical power. The low pressure steam coming out of the turbine is condensed to liquid by cooling after which the pressure of the relatively low temperature liquid is raised by a boiler feed pump or pumps to repeat the cycle. Rankine cycle efficiencies depend on plant size, fuel, and design and typically vary from about 10% for very small (< 1 MWe) solid-fueled systems to greater than 40% for large (>500 MWe) supercritical units. Typical solid-fueled biomass and waste fired power plants (~10-100 MWe) have net efficiencies of about 17-25%.

<sup>81</sup> Integrated gasifier combined cycles (IGCC), are combined cycle systems that incorporate a gasifier for the purposes of converting the solid fuel to a fuel gas for the gas turbine topping cycle. Combined cycle (CC) power systems can extract more useful energy from a given amount of input energy or fuel by utilizing two power cycles in combination: 1) a gas turbine topping cycle and 2) a steam bottoming cycle utilizing heat rejected in the gas turbine exhaust. In such systems, the steam boiler is conventionally referred to as a heat recovery steam generator (HRSG). Gas turbines require a very clean working fluid. Using gasified biomass or coal as a turbine fuel requires extensive cleanup before introduction to the turbine in direct fired systems similar to those employing natural gas fuel. Indirect gas turbines employ heat exchangers between the combustion products and the turbine working fluid to avoid turbine fouling from impurities, but are not yet commercial due to limitations in materials for high temperature heat exchangers. Gasification of solid fuels for IGCC is also not yet being done commercially. Gas cleaning is one of the primary technical hurdles for solid fuel gasification systems fueling internal combustion

efficiencies of 35% or above, but are not yet fully commercial. Natural gas fired combined cycles have electrical efficiencies above 55% by comparison, but utilize non-renewable fuel. The application of combined cycles to biogas produced by anaerobic digestion is a possibility but digesters tend to be small for the scales typically employed, and digestion of MSW or MSW organics is still developmental for the most part in North America. Biogas co-fired with natural gas in large combined cycle power plants is a way to improve net efficiency of biogas to electricity production if the opportunity exists. Fuel cells offer another high efficiency and clean option for biogas and fuel gases produced by thermochemical means, but these systems are also developmental and fuel purification is an issue.

In Table 1, the electrical generation estimates were simply calculated from the potential primary energy by applying the appropriate thermochemical or biochemical conversion efficiency and assuming an availability of 100% (meaning the conversion facilities operate only 100% of the time).

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engines including reciprocating (piston) engines and gas turbines (though piston engines have less stringent gas cleanliness requirements). Gasifiers are currently fueling boilers and have been used with coal for liquid fuels production, for example, the SASOL plant in South Africa. Natural gas and distillate fueled CC systems are fully commercial.